

# Different Statistical Methods Studying the Nature Relationships between Climatic Variables and Cotton Production

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## Article Information

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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. This study, predicting effects of climatic factors during different convenient intervals (in days) on cotton flower and boll production compared with daily observations and collect 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. 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.

## 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 [1]. 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 [2]. 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 [3]. Weather, soil, cultivars, and cultural practices affect crop growth interactively, sometimes resulting in plants responding in unexpected ways to their conditions [4].

Water is a primary factor controlling plant growth. Xiao et al. [5] 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 [6] 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 and plant biomass, and increased leaf temperature and specific leaf area.

Temperature is also a primary factor controlling rates of plant growth and development. Burke et al. [7] has 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. Hodges et al. [8] found that the optimum temperature for cotton stem and leaf growth, seedling development, and fruiting was almost 30°C, with fruit retention decreasing rapidly as the time of exposure to 40°C increased. Reddy et al. [9] found that when Upland cotton (*G. hirsutum*) cv. DPL-51 was grown in naturally lit plant growth chambers at 30/22°C day/night temperatures from sowing until flower bud production and at 20/12, 25/17,

30/22, 35/27 and 40/32°C for 42 days after flower bud production, fruit retention was severely curtailed at the two higher temperatures compared with 30/22°C. 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. Schrader et al. [10] stated that high temperatures that 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 [11].

Zhou et al. [12] 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

A- This study aimed at predicting effects of climatic factors during different convenient intervals (in days) on cotton flower and boll production compared with daily observations. The study presents a rich effort focused on evaluating the efficacy of regression equations between cotton crop data and climatic data grouped at different time intervals, to determine the appropriate time scale for aggregating climate data to be used for predicting flower and boll production in cotton.

B- And investigates and 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 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.

### Data and Methods

Two uniform field trials were conducted at the experimental farm of the Agricultural Research Center, Ministry of Agriculture, Giza, Egypt (30°N, 31°: 28'E at an altitude of 19 m), using the 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) [13].

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<sup>3</sup> h<sup>-1</sup>. 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<sup>-1</sup>. Phosphorus fertilizer was applied at a rate of 54 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> as calcium super phosphate during land preparation. Potassium fertilizer was applied at a rate of 57 kg K<sub>2</sub>O ha<sup>-1</sup> 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<sup>-1</sup> 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 [13].

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 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 20<sup>th</sup> 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 [13].

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<sub>1</sub>), number of retained bolls obtained from the total daily tagged flowers on all selected plants at harvest (Y<sub>2</sub>) and (Y<sub>3</sub>) 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 [13].

**Table 1:** Range and mean values of the independent variables for the two seasons and over all data.

Climatic factor's	First season*		Second season**		Over all data (Two seasons)	
	Range	Mean	Range	Mean	Range	Mean
Max Temp (°C), (X <sub>1</sub> )	31.0-44.0	34.3	30.6-38.8	34.1	30.6-44.0	34.2
Min Temp (°C), (X <sub>2</sub> )	18.6-24.5	21.9	18.4-23.9	21.8	18.4-24.5	21.8
Max-Min Temp (°C), (X <sub>3</sub> )*	9.4-20.9	12.4	8.5-17.6	12.2	8.5-20.9	12.3
Evap (mm d <sup>-1</sup> ), (X <sub>4</sub> )	7.6-15.2	10	4.1-9.8	6	4.1-15.2	8
0600 h Temp (°C), (X <sub>5</sub> )	14.0-21.5	17.8	13.3-22.4	18	13.3-22.4	17.9
1800 h Temp (°C), (X <sub>6</sub> )	19.6-27.0	24	20.6-27.4	24.2	19.6-27.4	24.1
Sunshine (h d <sup>-1</sup> ), (X <sub>7</sub> )	10.3-12.9	11.7	9.7-13.0	11.9	9.7-13.0	11.8
Max RH (%), (X <sub>8</sub> )	62-96	85.4	51-84	73.2	51-96	79.6
Min RH (%), (X <sub>9</sub> )	Nov-45	30.8	23-52	39.8	Nov-52	35.1
Wind speed (m s <sup>-1</sup> ), (X <sub>10</sub> )	ND	ND	2.2-7.8	4.6	ND	ND

\*Diurnal temperature range. ND not determined.

\*\*Flower and boll stage (68 days, from 23 June through 29 August). \*\*\*Flower and boll stage (62 days, from 29 June through 29 August) (Sawan et al. 2002).

The climatic factors (independent variables) considered were daily data of: maximum air temperature (°C, X<sub>1</sub>); minimum air temperature (°C, X<sub>2</sub>); maximum-minimum air temperature (diurnal temperature range) (°C, X<sub>3</sub>); evaporation (expressed as Piche evaporation) (mm day-1, X<sub>4</sub>); surface soil temperature, grass temperature or green cover temperature at 0600 h (°C, X<sub>5</sub>) and 1800 h (°C, X<sub>6</sub>); sunshine duration (h day-1, X<sub>7</sub>); Maximum Relative Humidity (maxRH) (%), X<sub>8</sub>, Minimum Relative Humidity (minRH) (%), X<sub>9</sub> and wind speed (m s-1, X<sub>10</sub>) 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 [14].

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 [14]. Range and mean values of the climatic parameters recorded during the production stage for both seasons and overall data are

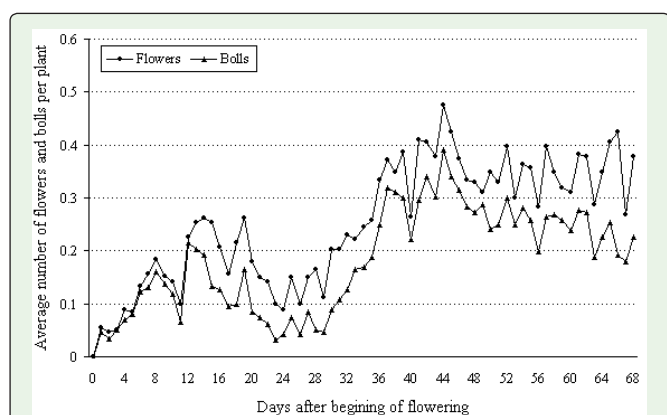
listed in Table 1 [15]. Daily number of flowers and number of bolls per plant which survived till maturity (dependent variables) during the production stage in the two seasons are graphically illustrated in Figures 1 and 2 [15].

## Results and Discussion

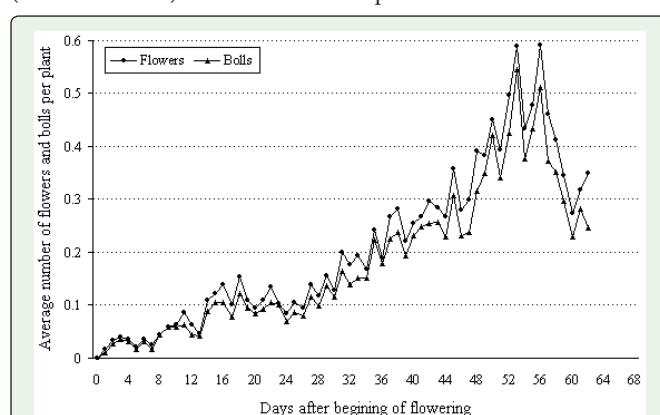
### Appropriate time scale for aggregating climatic data to predict flowering and boll setting behavior of cotton

#### Statistical Analysis

Statistical analysis was conducted using the procedures outlined in the General Linear Model (GLM, SAS Institute, Inc. 1985). Data of dependent and independent variables, collected for each day of the production stage (60 days in each season), were summed up into intervals of 2, 3, 4, 5, 6 or 10 days. Data from these intervals were used to compute relationships between the dependent variables (flower and boll setting and boll retention) and the independent variables (climatic factors) in the form of simple correlation coefficients for



**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<sup>3</sup>ha<sup>-1</sup>. No rainfall occurred during the growing season. The sampling size was 261 plants (Sawan et al. 2002).



**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<sup>3</sup>ha<sup>-1</sup>. No rainfall occurred during the growing season. The sampling size was 358 plants (Sawan et al. 2002).

each season. Comparisons between the values of “r” were done to determine the best interval of days for determining effective relationships. The  $\alpha$ -level for significance was  $P < 0.15$ . The climatic factors attaining a probability level of significance not exceeding 0.15 were deemed important (affecting the dependent variables), selected and combined with dependent variable in multiple regression analysis to obtain a convenient predictive equation [16]. Multiple linear regression equations (using stepwise method) comprising selected predictive variables were computed for the determined interval and 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 analyses were computed according to Draper and Smith [17].

**Correlation estimates between the production variables and studied climatic factors for different intervals of days in each season (I and II):** Significant simple correlation coefficients were estimated between the production variables and studied climatic factors for different intervals of days in each season (I and II) (Tables 2 and 3) [15]. According to these correlation coefficients, it could be seen that all significant relationships were negative except for the positive relationships between maximum relative humidity in the first season and minimum relative humidity in both seasons.

Evaporation was the most important climatic factor affecting flower and boll production in Egyptian cotton. The negative correlation means that high evaporation rates significantly reduce flower and boll production. High evaporation rates could result in water stress that would slow growth and increase shedding rate of flower and boll production [15]. Kaur and Singh [18] found in cotton that flower number was decreased by water stress, particularly when applied at flowering. Seed cotton yield was about halved by water stress applied at flowering, slightly decreased by stress at boll formation, and not significantly affected by stress in the vegetative stage (6-7 wk after sowing). Orgaz et al. [19], in field experiments at Cordoba, southwest Spain, grew cotton cvs. Acala SJ-C1, GC-510, Coker-310 and Jean at Evapotranspiration (ET) levels generated with sprinkler line irrigation from 40 to 100% of maximum ET ( $ET_{max}$ ). The water production function of Jean cultivar was linear; seed yield was 5.30 t ha<sup>-1</sup> at  $ET_{max}$  (820 mm). In contrast, the production function of the three other cultivars was linear up to 85% of  $ET_{max}$ , but leveled off as ET approached  $ET_{max}$  (830 mm) because a fraction of the set bolls did not open by harvest at high ET levels. These authors concluded that it is possible to define an optimum ET deficit for cotton based on cultivar earliness, growing-season length and availability of irrigation water.

**Table 2:** Significant simple correlation coefficient values between the production variables and the studied climatic factors for the daily and different intervals of days in first season.

Intervals of days	Production variables	Temp. (°C)		Max.-Min. (°C)	Evap. (mm d <sup>-1</sup> )	Surface soil temp. (°C)		Sunshine duration	R. humidity (%)	
		Max. (X <sub>1</sub> )	Min. (X <sub>2</sub> )	(X <sub>3</sub> )	(X <sub>4</sub> )	0600 h (X <sub>5</sub> )	1800 h (X <sub>6</sub> )	(h d <sup>-1</sup> ) (X <sub>7</sub> )	Max.(X <sub>8</sub> )	Min.(X <sub>9</sub> )
Daily (n = 60)	Flower	NS	NS	NS	-0.48**	NS	NS	-0.22**	0.25 <sup>†</sup>	NS
	Boll	NS	NS	NS	-0.48**	NS	NS	-0.14*	0.39**	NS
	Boll reten. ratio	NS	NS	NS	-0.26 <sup>†</sup>	NS	NS	NS	0.20 <sup>†</sup>	NS
2 Days (n = 30)	Flower	NS	NS	NS	-0.60**	NS	NS	-0.30**	0.33**	0.21*
	Boll	NS	NS	NS	-0.56**	NS	NS	NS	0.33**	NS
	Boll reten. ratio	NS	NS	NS	-0.27**	NS	NS	NS	NS	NS
3 Days (n = 20)	Flower	NS	NS	NS	-0.68**	NS	NS	-0.32*	0.39**	0.29*
4 Days (n = 15)	Boll	NS	NS	NS	-0.63**	NS	NS	NS	0.36**	NS
	Boll reten. ratio	NS	NS	NS	-0.31*	-0.24*	NS	NS	NS	NS
	Flower	NS	NS	NS	-0.71**	NS	NS	-0.35*	0.36**	0.25*
	Boll	NS	NS	NS	-0.64**	NS	NS	-0.23*	0.38**	NS
	Boll reten. ratio	NS	NS	NS	-0.29*	NS	NS	NS	NS	NS
5 Days (n = 12)	Flower	NS	NS	NS	-0.76**	NS	NS	-0.57**	0.62 <sup>†</sup>	NS
	Boll	NS	NS	NS	-0.71**	NS	NS	-0.55**	0.59**	NS
	Boll reten. ratio	NS	NS	NS	-0.58**	-0.30*	NS	-0.47*	0.54**	NS
6 Days (n = 10)	Flower	NS	NS	NS	-0.73**	NS	NS	-0.44*	0.46*	0.40*
	Boll	NS	NS	NS	-0.69*	NS	NS	NS	0.41*	NS
	Boll reten. ratio	NS	NS	NS	-0.36*	-0.39*	NS	NS	NS	NS
10 Days (n = 6)	Flower	NS	NS	NS	-0.79*	NS	NS	-0.57**	0.79 <sup>†</sup>	NS
	Boll	NS	NS	NS	-0.71**	NS	NS	-0.40*	0.71**	NS
	Boll reten. ratio	NS	NS	NS	-0.39*	-0.35*	NS	NS	NS	NS

\*\* , \* , \*\* , \* Significant at the 1%, 5%, 10% and 15% probability levels, respectively. NS was not significant.

<sup>†</sup>Wind speed did not show significant effect upon the studied production variables.

<sup>‡</sup>n = Number of data pairs used in calculations (Sawan et al. 2002).



The second most important climatic factor in our study was relative humidity. Effect of maximum relative humidity varied markedly from the first season to the second. While it was significantly correlated with the dependent variables in the first season, the inverse pattern was true in the second season. The diverse effect may be due to the differences in the mean values of this factor in the two seasons; where it was on average, about 86% in the first season and only 72% in the second season (Table 1) [15].

The third most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with fruit production except for boll production in the first season, which was not significant [20]. The negative relationship between sunshine duration and cotton production may be due to the fact that the species of the genus *Gossypium spp.* are known to be short day plants. So, an increase in sunshine duration above that sufficient to attain good plant growth will decrease flower and boll production. Bhatt [21] found that exposure to daylight over 14 h and high day temperature, individually or in combination, delayed flowering of the Upland cotton cv. J34. Although average sunshine duration in our study was only 11.7 h, it did range up to 13 h, which, in combination with high maximum temperatures (up to 38.8°C), may have adversely affected reproductive growth.

Results obtained from the productive stage of each season individually, indicated that relationships of some climatic variables with the dependent variables varied markedly from one season to another (Tables 2 and 3). This may be due to the differences between climatic factors in the two seasons as illustrated by the ranges and means shown in Table 1. For example, maximum temperature, temperature magnitude and surface soil temperature at 1800 h did not show significant relations in the first season, but they were related to boll production in the second season. Meanwhile, the least important factors were surface soil temperature at 0600 h and minimum temperature [15].

Our results indicate that evaporation was the most effective and consistent climatic factor affecting boll production (Tables 2 and 3). As the sign of the relationship was negative, this means that an increase in evaporation caused a significant reduction in boll number. Thus, applying specific treatments, such as an additional irrigation or the use of Plant Growth Regulators (PGR) that would decrease the deleterious effect of evaporation after boll formation, could contribute to an increase in cotton boll production and retention, and consequently an increase in cotton yield [22]. In this connection, Moseley et al. [23] found that methanol increased water use efficiency, growth and development of cotton cv. DPL-50 plants

**Table 3:** Significant simple correlation coefficient values between the production variables and the studied climatic factors for the daily and different intervals of days in second season.

Intervals of days	Production variables	Temp. (°C)		Max.-Min. (°C)	Evap. (mm d-1)	Surface soil temp. (°C)		Sunshine duration	R. humidity (%)	
		Max. (X <sub>1</sub> )	Min. (X <sub>2</sub> )	(X <sub>3</sub> )	(X <sub>4</sub> )	0600 h (X <sub>5</sub> )	1800 h (X <sub>6</sub> )	(h d <sup>-1</sup> ) (X <sub>7</sub> )	Max.(X <sub>8</sub> )	Min.(X <sub>9</sub> )
Daily (n <sup>v</sup> = 60)	Flower	-0.41 <sup>**</sup>	NS	-0.34 <sup>*</sup>	-0.60 <sup>**</sup>	NS	-0.36 <sup>**</sup>	-0.35 <sup>*</sup>	NS	0.46 <sup>**</sup>
	Boll	-0.21 <sup>+</sup>	NS	-0.37 <sup>**</sup>	-0.42 <sup>**</sup>	NS	-0.32 <sup>*</sup>	-0.25 <sup>*</sup>	NS	0.42 <sup>**</sup>
	Boll reten. ratio	NS	0.20 <sup>+</sup>	-0.30 <sup>**</sup>	-0.44 <sup>**</sup>	NS	-0.18 <sup>+</sup>	0.21 <sup>+</sup>	-0.41 <sup>**</sup>	0.40 <sup>**</sup>
2 Days (n = 30)	Flower	-0.47 <sup>**</sup>	NS	NS	-0.70 <sup>**</sup>	NS	-0.41 <sup>*</sup>	-0.44 <sup>*</sup>	NS	0.55 <sup>**</sup>
	Boll	-0.47 <sup>**</sup>	NS	NS	-0.70 <sup>**</sup>	NS	-0.41 <sup>*</sup>	-0.44 <sup>*</sup>	NS	0.55 <sup>**</sup>
	Boll reten. ratio	NS	NS	-0.36 <sup>*</sup>	NS	NS	NS	NS	NS	0.22 <sup>+</sup>
3 Days (n = 20)	Flower	NS	NS	-.45 <sup>*</sup>	-0.71 <sup>**</sup>	NS	-0.47 <sup>*</sup>	-0.54 <sup>*</sup>	NS	0.55 <sup>**</sup>
	Boll	NS	NS	-0.46 <sup>*</sup>	-0.70 <sup>**</sup>	NS	-0.46 <sup>*</sup>	-0.55 <sup>**</sup>	NS	0.55 <sup>**</sup>
	Boll reten. ratio	NS	NS	-0.28 <sup>+</sup>	-0.22 <sup>+</sup>	NS	NS	-0.32 <sup>+</sup>	NS	0.25 <sup>+</sup>
4 Days (n = 15)	Flower	NS	NS	-0.49 <sup>**</sup>	-0.68 <sup>**</sup>	NS	-0.49 <sup>**</sup>	-0.45 <sup>**</sup>	NS	0.54 <sup>*</sup>
	Boll	NS	NS	-0.50 <sup>*</sup>	-0.73 <sup>**</sup>	NS	-0.48 <sup>**</sup>	-0.53 <sup>*</sup>	NS	0.57 <sup>*</sup>
	Boll reten. ratio	NS	NS	-0.41 <sup>**</sup>	-0.43 <sup>**</sup>	NS	NS	-0.54 <sup>*</sup>	NS	0.47 <sup>**</sup>
5 Days (n = 12)	Flower	NS	NS	-0.51 <sup>**</sup>	-0.81 <sup>**</sup>	NS	-0.58 <sup>*</sup>	-0.62 <sup>*</sup>	NS	0.65 <sup>*</sup>
	Boll	NS	NS	-0.51 <sup>**</sup>	-0.80 <sup>**</sup>	NS	-0.59 <sup>*</sup>	-0.61 <sup>*</sup>	NS	0.65 <sup>*</sup>
	Boll reten. ratio	NS	NS	-0.46 <sup>+</sup>	NS	NS	-0.57 <sup>*</sup>	NS	NS	0.59 <sup>*</sup>
6 Days (n = 10)	Flower	NS	NS	-0.53 <sup>**</sup>	-0.78 <sup>**</sup>	NS	-0.62 <sup>*</sup>	-0.66 <sup>*</sup>	NS	0.61 <sup>*</sup>
	Boll	NS	NS	-0.55 <sup>**</sup>	-0.78 <sup>**</sup>	NS	-0.63 <sup>*</sup>	-0.66 <sup>*</sup>	NS	0.62 <sup>*</sup>
	Boll reten. ratio	NS	NS	-0.80 <sup>**</sup>	-0.65 <sup>*</sup>	NS	NS	-0.66 <sup>*</sup>	NS	0.69 <sup>*</sup>
10 Days (n = 6)	Flower	NS	NS	-0.67 <sup>**</sup>	-0.39 <sup>+</sup>	NS	-0.52 <sup>+</sup>	-0.69 <sup>**</sup>	NS	0.67 <sup>**</sup>
	Boll	NS	NS	-0.64 <sup>**</sup>	-0.43 <sup>+</sup>	NS	-0.48 <sup>+</sup>	-0.70 <sup>**</sup>	NS	0.72 <sup>**</sup>
	Boll reten. ratio	NS	NS	NS	-0.35 <sup>+</sup>	NS	-0.32 <sup>+</sup>	-0.34 <sup>+</sup>	NS	NS

<sup>\*\*</sup>, <sup>\*</sup>, <sup>+</sup>, <sup>+</sup> Significant at the 1%, 5%, 10% and 15% probability levels, respectively. NS was not significant.

<sup>v</sup>Wind speed did not show significant effect upon the studied production variables..

<sup>v</sup>n = Number of data pairs used in calculations (Sawan et al. 2002).

in arid conditions, under intense sunlight. They also found that irrigation (a total of 11.4 cm applied in July) increased lint yield by 18%. Zhao and Oosterhuis [24] found that under water deficit stress, in a growth chamber, cotton (*G. hirsutum*) cv. Stoneville 506 plants treated with the plant growth regulator PGR-IV (gibberellic acid, IBA and a proprietary fermentation broth) had significantly higher dry weights of roots and floral buds than the untreated water-stressed plants. They concluded that PGR-IV could partially alleviate the detrimental effects of water stress on photosynthesis and dry matter accumulation and improve the growth and nutrient absorption of growth chamber-grown cotton plants. Meek et al. [25] in a field experiment in Arkansas found that application of 3 or 6 kg glycine betaine (PGR) ha<sup>-1</sup> to cotton plants under mild water stress increased yield.

Comparing results of both seasons for the different intervals of days with those from daily observation, the 5-d interval had the highest R<sup>2</sup> values (Tables 2 and 3). Therefore, it would be the most efficient interval to use to help circumvent the unfavorable effect of climatic factors. It was also more convenient to use since it possessed less data pairs (n = 12). This finding gives researchers and producers a chance to deal with condensed rather than daily weather data [15].

**Regression models:** Multiple linear regression equations were estimated using stepwise multiple regression technique to express the relation between cotton production variables [number of flowers (Y<sub>1</sub>) and bolls per plant (Y<sub>2</sub>); and boll retention ratio (Y<sub>3</sub>)] and the studied climatic factors (Table 4). Evaporation, sunshine duration and relative humidity accounted for a highly significant amount of variation (P<0.05) in cotton production variables, with the equation obtained for the 5-d interval showing a high degree of certainty. The R<sup>2</sup> values for the 5-d interval were higher than those obtained from daily data for each of the cotton production variables. Also, the 5-d interval gave more efficient and stable estimates than the other intervals studied (data not shown). The R<sup>2</sup> values for these equations clearly indicate the importance of such equations since the climatic factors

explained about 54 to 68% of the variations found in the dependent variables. The equations are for single years which as the production variables had inconsistent impacts in the different years. Therefore the equations cannot be generalized over years. However, equations of the first season could be applied if the maximum relative humidity (%) is more than twice the minimum relative humidity (%) during the same interval: i.e., (mean max. relt. hum. %)/(mean min. relt. hum. %) = 86.6/31.0 = 2.97 (Table 1). The equation from the second season could be applied when the ratio was less than two: i.e. (mean max. relt. hum. %)/( mean min. relt. hum. %) = 73.1/39.7 = 1.84 (Table 1) [15]. Other workers, studying the effect of climatic factors on cotton boll production and retention and, in turn, yield and have found different relationships. Other researchers have found that temperature is often the major factor affecting cotton growth. Reddy et al. [26] observed that when cotton cv. DPL-51 was grown in controlled environments with natural solar radiation, flower and fruit retention was very low at an ambient temperature ranging from 31.3 to 33°C plus 5 or 7°C and concluded that cotton could be severely damaged by temperatures above those found during midsummer in the cotton belt in the United States of America. In our study, maximum temperatures were above the optimum for cotton growth found by Mergeai and Demol [27]; however, the minimum temperature during this period was 22°C, which, combined with short days (11.8 h), probably favored growth. Therefore, temperature conditions during reproductive growth of cotton in Egypt were not limiting growth.

**Correlation estimates between the production variables and studied climatic factors for different intervals of days (combined data of the 2 seasons):** Significant simple correlation coefficients were estimated between the production variables and studied climatic factors for different intervals of days (combined data of the 2 seasons) (Table 5) [15].

Evaporation was the most important climatic factor affecting flower and boll production in Egyptian cotton. The negative correlation means that high evaporation ratio significantly reduced

**Table 4:** The equations obtained for each of the studied cotton production variables for five-day intervals and daily intervals in the two seasons.

Season	Equation <sup>2</sup>	R <sup>2</sup>	Significance
<b>Five-day intervals</b>			
<b>First</b>	$Y_1 = 20.54 - 0.6359X_4 - 0.419X_7 + 0.0263X_8$	0.6255	**
	$Y_2 = 12.63 - 0.2007X_4 - 0.7234X_7 + 0.1047X_8$	0.5367	**
	$Y_3 = 75.254 - 0.0728X_4 - 0.2607X_7 + 0.1921X_8$	0.5892	**
<b>Second</b>	$Y_1 = 28.63 - 0.4173X_3 - 0.2526X_4 - 0.1147X_6 - 0.0943X_7 + 0.0472X_9$	0.6832	**
	$Y_2 = 17.45 - 0.3065X_3 - 0.4172X_4 - 0.1259X_6 - 0.08769X_7 + 0.0698X_9$	0.6385	**
	$Y_3 = 67.45 - 0.3852X_3 - 0.1988X_6 + 0.25483X_9$	0.6518	**
<b>Daily intervals</b>			
<b>First</b>	$Y_1 = 21.27 - 0.9472X_4 - 0.218X_7 + 0.1163X_8$	0.5163	**
	$Y_2 = 16.85 - 1.743X_4 - 0.3419X_7 + 0.1694X_8$	0.4651	**
	$Y_3 = 70.63 - 0.1362X_4 - 0.2352X_7 + 0.2076X_8$	0.4722	**
<b>Second</b>	$Y_1 = 25.81 - 0.3854X_3 - 0.2278X_4 - 0.0894X_6 - 0.1016X_7 + 0.0765X_9$	0.5714	**
	$Y_2 = 19.47 - 0.5644X_3 - 0.2763X_4 - 0.1132X_6 - 0.0947X_7 + 0.0485X_9$	0.5436	**
	$Y_3 = 69.32 - 0.3461X_3 - 0.1609X_7 + 0.1274X_9$	0.4961	**

<sup>2</sup>Where Y<sub>1</sub> = number of flowers per plant, Y<sub>2</sub> = number of bolls per plant, Y<sub>3</sub> = boll retention ratio, X<sub>3</sub> = maximum - minimum temperature °C, X<sub>4</sub> = evaporation mm day<sup>-1</sup>, X<sub>6</sub> = surface soil temperature °C at 1800 h., X<sub>7</sub> = sunshine duration h day<sup>-1</sup>, X<sub>8</sub> = maximum humidity % and X<sub>9</sub> = minimum humidity %. (Sawan et al. 2002).

flower and boll production. High 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 was minimum relative humidity, which had a high positive correlation with flower and boll production, and retention ratio. The positive correlation means that increased humidity would bring about better boll production. The third most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with flower and boll production only [15].

Maximum air temperature, temperature magnitude and surface soil temperature at 1800 h show significant negative relationships with flower and boll production only. Meanwhile, the least important factors were surface soil temperature at 0600 h and minimum air temperature [15].

Our results indicate that evaporation was the most effective climatic factor affecting cotton boll production. As the sign of the relationship was negative, this means that an increase in evaporation caused a significant reduction in boll number [15]. Thus, applying specific treatments, such as an additional irrigation or the use of Plant Growth Regulators (PGR) that would decrease the deleterious effect

of evaporation after boll formation, could contribute to an increase in cotton boll production and retention, and consequently an increase in cotton yield [20].

Comparing results for the different intervals of days with those from daily observation (Table 5), the 5-day interval appeared to be the most suitable interval, which actually revealed a more solid and more obvious relationships between climatic factors and production characters. This was in fact indicated by the higher R<sup>2</sup> values obtained when using the 5-day intervals. The 5-day interval may be the most suitable interval for diminishing the daily fluctuations between the factors under study to clear these relations comparing with the other intervals. However, it seems that this conception is true provided that the fluctuations in climatic conditions are limited or minimal. Therefore, it would be the most efficient interval used to help circumvent the unfavorable effect of climatic factors. This finding gives researchers and producers a chance to deal with condensed rather than daily weather data [15].

**Regression models:** Multiple linear regression equations were estimated using the stepwise multiple regression technique to express the relation between cotton production variables [number of flowers

**Table 5:** Significant simple correlation coefficient values between the production variables and the studied climatic factors for the daily and different intervals of days combined over both seasons.

Daily and intervals of days	Production variables	Air temp (°C)			Evap (mm d-1) (X <sub>4</sub> )	Surface soil temp (°C)		Sunshine duration (hd <sup>-1</sup> ) (X <sub>7</sub> )	Relative humidity (%)	
		Max (X <sub>1</sub> )	Min (X <sub>2</sub> )	Max-Min (X <sub>3</sub> )		0600h (X <sub>5</sub> )	1800h (X <sub>6</sub> )		Max (X <sub>8</sub> )	Min (X <sub>9</sub> )
Daily (n=120)	Flower	-0.15**	NS	-0.26**	-0.33**	NS	-0.20*	-0.23*	NS	0.30**
	Boll	NS	NS	-0.25**	-0.43**	NS	-0.19**	-0.18**	NS	0.36**
	Boll ret. rat.	NS	NS	NS	-0.56**	NS	NS	NS	NS	0.34**
2 Days (n <sup>#</sup> = 60)	Flower	-0.31**	NS	-0.32*	-0.36**	NS	-0.24*	-0.36**	NS	0.37**
	Boll	-0.29**	NS	-0.30**	-0.46**	NS	-0.21*	-0.31*	NS	0.44**
	Boll ret. rat.	NS	NS	NS	-0.61**	NS	NS	NS	NS	0.40**
3 Days (n <sup>#</sup> = 40)	Flower	-0.34*	NS	-0.34*	-0.33*	NS	-0.28**	-0.39*	NS	0.34*
	Boll	-0.32*	NS	-0.32*	-0.48**	NS	-0.24*	-0.36*	NS	0.45**
	Boll ret. rat.	NS	NS	NS	-0.63**	NS	NS	NS	NS	0.40*
4 Days (n <sup>#</sup> =30)	Flower	-0.31**	NS	-0.35**	-0.33**	NS	-0.28*	-0.39*	NS	0.34**
	Boll	-0.31**	NS	-0.33**	-0.48**	NS	-0.23*	-0.38*	NS	0.45*
	Boll ret. rat.	NS	NS	NS	-0.64**	NS	NS	NS	NS	0.42*
5 Days (n <sup>#</sup> = 24)	Flower	-0.35**	NS	-0.37**	-0.39**	NS	-0.39**	-0.52**	NS	0.41*
	Boll	-0.33*	NS	-0.35**	-0.49*	NS	-0.35**	-0.44*	NS	0.47**
	Boll ret. rat.	NS	NS	NS	-0.66**	NS	NS	NS	NS	0.43*
6 Days (n <sup>#</sup> = 20)	Flower	-0.37**	NS	-0.41**	-0.38**	NS	NS	-0.54**	NS	0.42*
	Boll	-0.37**	NS	-0.40**	-0.49*	NS	NS	-0.46*	NS	0.49*
	Boll ret. rat.	NS	NS	NS	-0.69**	NS	NS	NS	NS	0.45*
10 Days (n <sup>#</sup> =12)	Flower	NS	NS	-0.45**	-0.40*	NS	-0.55*	-0.65*	NS	0.43**
	Boll	NS	NS	-0.43**	-0.51**	NS	-0.53**	-0.57*	NS	0.51**
	Boll ret. rat.	NS	NS	NS	-0.74**	NS	NS	NS	NS	0.55*

<sup>#</sup>Wind speed did not show significant effect upon the studied production variables, so is not reported.

\*\*Significant at 1 % probability level, \* Significant at 5 % probability level.

\*\*Significant at 10 % probability level, + Significant at 15 % probability level.

NS Means simple correlation coefficient is not significant at the 15% probability level.

<sup>#</sup>n = Number of data pairs used in calculation (Sawan et al. 2002).

**Table 6:** The equations obtained for each of the studied cotton production variables for the five-day intervals and daily intervals combined over both seasons.

Equation <sup>z</sup>	R <sup>2</sup>	Significance
<b>Five-day intervals</b>		
Y1 = 23.78 – 0.5362X4 – 0.1429X6 – 0.1654X7 + 0.0613X9	0.6237	**
Y2 = 15.89 – 0.4762X4 – 0.1583X6 – 0.1141X7 + 0.0634X9	0.5945	**
Y3 = 72.65 – 0.0833X4 – 0.1647X6 + 0.2278X9	0.6126	**
<b>Daily intervals</b>		
Y1 = 19.78 – 0.181X3 – 0.069X4 – 0.164X6 – 0.182X7 + 0.010X9	0.4117	**
Y2 = 14.96 – 0.173X3 – 0.075X4 – 0.176X6 – 0.129X7 + 0.098X9	0.4461	**
Y3 = 52.36 – 3.601X4 – 0.2352X7 + 4.511X9	0.3587	**

<sup>z</sup>Where Y<sub>1</sub> = number of flowers per plant, Y<sub>2</sub> = number of bolls per plant, Y<sub>3</sub> = boll retention ratio, X<sub>3</sub> = maximum – minimum temperature °C, X<sub>4</sub> = evaporation mm day<sup>-1</sup>, X<sub>6</sub> = surface soil temperature °C at 1800 h., X<sub>7</sub> = sunshine duration h day<sup>-1</sup> and X<sub>9</sub> = minimum relative humidity % (Sawan et al. 2002).

(Y<sub>1</sub>); bolls per plant (Y<sub>2</sub>); and boll retention ratio (Y<sub>3</sub>) and the studied climatic factors (Table 6) [15].

Evaporation and surface soil temperature at 1800 h, sunshine duration and minimum humidity accounted for a highly significant amount of variation (P<0.05) in cotton production variables, with the equation obtained for the 5-day interval showing a high degree of certainty. The R<sup>2</sup> values for the 5-day interval were higher than those obtained from daily data for each of the cotton production variables. Also, the 5-day interval gave more efficient and stable estimates than the other studied intervals (data not shown). The R<sup>2</sup> values for these equations clearly indicate the importance of such equations since the climatic factors involved explained about 59 to 62% of the variation found in the dependent variables [15].

During the production stage, an accurate weather forecast for the next 10 days would provide an opportunity to avoid any adverse effect for weather factors on cotton production through applying appropriate cultural practices such as adequate irrigation regime or utilization of plant growth regulators. This proposal would be true if the fluctuations in weather conditions were not extreme. Our recommendation would be the accumulation 5-day climatic data, and

use this information to select the adequate cultural practices (such as an additional irrigation or utilization of plant growth regulators) that would help circumvent the unfavorable effects of climatic factors. In case of sharp fluctuations in climatic factors, data could be collected daily, and when stability of climatic conditions is restored, the 5-day accumulation of weather data could be used again [15].

Relative humidity showed the highest contribution to the variation in both flower and boll production. This finding can be explained in the light of results found by Ward and Bunce [28] 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.

Regression models obtained explained a sensible proportion of the variation in flower and boll production, as indicated by their R<sup>2</sup>, which ranged between 0.53-0.72 [13]. These results agree with Miller et al. [29] in their regression study of the relation of yield with rainfall and temperature. They suggested that the other R<sup>2</sup> 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

**Table 7:** 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 <sup>*</sup>				Second season <sup>**</sup>			
	Mean	S.D.	Max.	Min.	Mean	S.D.	Max.	Min.
Max temp [°C] (X <sub>1</sub> )	34.1	1.2	44	31	33.8	1.2	38.8	30.6
Min temp [°C] (X <sub>2</sub> )	21.5	1	24.5	18.6	21.4	0.9	24.3	18.4
Max-Min temp [°C] (X <sub>3</sub> ) <sup>*</sup>	12.6	1.1	20.9	9.4	12.4	1.3	17.6	8.5
Evapor [mm d <sup>-1</sup> ] (X <sub>4</sub> )	10.6	1.6	16.4	7.6	6	0.7	9.8	4.1
0600 h temp [°C] (X <sub>5</sub> )	17.5	1.1	21.5	13.9	17.6	1.2	22.4	13.3
1800 h temp [°C] (X <sub>6</sub> )	24.2	1.9	32.3	19.6	23.7	1.1	27.4	20.6
Sunshine [h d <sup>-1</sup> ] (X <sub>7</sub> )	11.7	0.8	12.9	9.9	11.7	0.4	13	10.3
Max hum [%] (X <sub>8</sub> )	85.6	3.3	96	62	72.9	3.8	84	51
Min hum [%] (X <sub>9</sub> )	30.2	5.2	45	11	39.1	5	52	23
Wind speed [m s <sup>-1</sup> ] (X <sub>10</sub> )	ND	ND	ND	ND	4.6	0.9	7.8	2.2

<sup>\*</sup>Flower and boll stage (68 days, from 23 June through 29 August).

<sup>\*\*</sup>Flower and boll stage (62 days, from 29 June through 29 August).

<sup>\*</sup>diurnal temperature range.

ND not determined (Sawan et al. 2005).



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.

Temperature conditions during the reproduction growth stage of cotton in Egypt do not appear to limit this growth even though they are above the optimum for cotton growth [13]. A possible reason for that contradiction is that the effects of soil moisture status and relative humidity were not taken into consideration in the research studies conducted by other researchers in other countries. Since temperature and evaporation are closely related to each other, the higher evaporation rate could possibly mask the effect of temperature [20]. Sunshine duration and minimum relative humidity appeared to have secondary effects, yet they are in fact important factors. The importance of sunshine duration has been eluded by Moseley et al. [23] and Oosterhuis [30].

During production stage, an accurate weather forecast for the next 10 d would provide an opportunity to avoid any adverse effect of weather factors on cotton production, through applying appropriate cultural practices such as adequate irrigation or utilization of plant growth regulators [22]. This proposal would be true if the fluctuations in weather conditions were not extreme. Our recommendation would be to accumulate climatic data for 5 d and use this information to select adequate cultural practices (such as an additional irrigation or the utilization of plant growth regulators) that would help circumvent the unfavorable effects of climatic factors. In case of sharp fluctuations in climatic factors, data could be collected daily and when stability of climatic conditions was restored, the 5-d accumulation of weather data could be used again [15].

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

The effects of specific climatic factors during both pre- and 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 [14]. 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 7) [14].

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 [14]. The following 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 [14].

**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 8 and 9) revealed the following [14]:

**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 8). 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 (Table 8) [14]. 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 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 9) [14].

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. Daily maximum humidity showed insignificant correlation with both flower and boll production except for one day period only (the 15<sup>th</sup> 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 [14].

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-afternoon photosynthetic rates even under well-watered conditions. Boyer et al. [31] found that soybean plants with ample water supplies can experience water deficits due to high transpiration rates. Also, Human et al. [32] stated that, when sunflower plants were grown

**Table 8:** 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 <sup>-1</sup> )	Surface soil temp. (°C)		Sunshine duration (h d <sup>-1</sup> )	Humidity (%)	
		Max. (X <sub>1</sub> )	Min. (X <sub>2</sub> )	Max-Min* (X <sub>3</sub> )	(X <sub>4</sub> )	0600 h (X <sub>5</sub> )	1800 h (X <sub>6</sub> )	(X <sub>7</sub> )	Max. (X <sub>8</sub> )	Min. (X <sub>9</sub> )
0 <sup>#</sup>	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**	0.44**	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).

under controlled temperature regimes, water stress during budding, anthesis and seed filling, the CO<sub>2</sub> 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 10 and 11) [14] revealed the following:

**First season:** Daily evaporation showed significant negative correlation with number of bolls for all the 15 day periods after flowering (Table 10). Meanwhile its relationship with 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

**Table 9:** Simple correlation coefficients (r) between climatic factors<sup>2</sup> 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.(mmd-)	Surface Soil temp. (°C)		Sunshine duration(h d-1)	Humidity (%)	
		Max.(x <sub>1</sub> )	Min (x <sub>2</sub> )	Max-Min(x <sub>3</sub> )	(x <sub>4</sub> )	0600h(x <sub>5</sub> )	1800h(x <sub>6</sub> )	(x <sub>7</sub> )	(X <sub>8</sub> )	(X <sub>9</sub> )
0 <sup>#</sup>	Flower	-0.42**	0	-0.36**	-0.61**	-0.14	-0.37**	-0.37**	0.01	0.45**
	Boll	-0.42**	0.02	-0.37**	-0.59**	-0.13	-0.36**	-0.36**	0.01	0.46**
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.

<sup>#</sup>0 = Initial time.

\*Diurnal temperature range.

<sup>2</sup>Wind speed did not show significant effect upon the studied production variables, so it is not reported (Sawan et al. 2005).

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 11)

[14]. 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. 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.

**Table 10:** 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 <sup>-1</sup> )	Surface soil temp. (°C)		Sunshine duration (h d <sup>-1</sup> )	Humidity (%)	
		Max. (X <sub>1</sub> )	Min. (X <sub>2</sub> )	Max-Min* (X <sub>3</sub> )	(X <sub>4</sub> )	0600 h (X <sub>5</sub> )	1800 h (X <sub>6</sub> )	(X <sub>7</sub> )	Max. (X <sub>8</sub> )	Min. (X <sub>9</sub> )
0 <sup>#</sup>	Retention ratio	-0.05	-0.03	-0.03	-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	-0.1	-0.11	-0.28*	0	-0.11	-0.13	0.17	0.15

\*and \*\*Significant at 5% and 1% levels of significance, respectively.

<sup>#</sup>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).

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<sup>-1</sup> and 5.9 mm d<sup>-1</sup> in the first and second seasons, respectively [14].

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

**Table 11:** Simple correlation coefficient (r) values between climatic factors z 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.(mmd <sup>-1</sup> )	Surface Soil temp. (°C)		Sunshine duration(h d <sup>-1</sup> )	Humidity (%)	
		Max (X <sub>1</sub> )	Min (X <sub>2</sub> )	Max- Min <sup>*</sup> (X <sub>3</sub> )		(X <sub>4</sub> )	(X <sub>5</sub> )		(X <sub>6</sub> )	(X <sub>7</sub> )
0 <sup>#</sup>	Retention ratio <sup>*</sup>	-0.04	0.2	-0.31 <sup>*</sup>	-0.14	0.12	-0.2	0.01	-0.04	0.17
	No. of bolls	-0.42 <sup>**</sup>	0.02	-0.37 <sup>**</sup>	-0.59 <sup>**</sup>	-0.13	-0.36 <sup>**</sup>	-0.36 <sup>**</sup>	0.01	0.46 <sup>**</sup>
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 <sup>*</sup>	-0.01	-0.36 <sup>**</sup>	-0.63 <sup>**</sup>	-0.15	-0.30 <sup>*</sup>	-0.25 <sup>*</sup>	0.06	0.44 <sup>**</sup>
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 <sup>**</sup>	-0.65 <sup>**</sup>	-0.11	-0.25 <sup>*</sup>	-0.32 <sup>*</sup>	0.13	0.43 <sup>**</sup>
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 <sup>*</sup>	-0.62 <sup>**</sup>	-0.05	-0.28 <sup>*</sup>	-0.31 <sup>*</sup>	0.14	0.33 <sup>**</sup>
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 <sup>*</sup>	-0.63 <sup>**</sup>	-0.06	-0.25 <sup>*</sup>	-0.33 <sup>**</sup>	0.15	0.32 <sup>*</sup>
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 <sup>*</sup>	-0.62 <sup>**</sup>	-0.06	-0.24 <sup>*</sup>	-0.35 <sup>**</sup>	0.15	0.31 <sup>*</sup>
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 <sup>**</sup>	-0.08	-0.25 <sup>*</sup>	-0.34 <sup>**</sup>	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 <sup>**</sup>	-0.1	-0.29 <sup>*</sup>	-0.32 <sup>*</sup>	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 <sup>**</sup>	-0.1	-0.28 <sup>*</sup>	-0.32 <sup>*</sup>	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 <sup>*</sup>	-0.62 <sup>**</sup>	-0.11	-0.30 <sup>*</sup>	-0.33 <sup>**</sup>	0.13	0.27 <sup>*</sup>
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 <sup>*</sup>	-0.07	-0.30 <sup>*</sup>	-0.60 <sup>**</sup>	-0.16	-0.34 <sup>**</sup>	-0.34 <sup>**</sup>	0.11	0.26 <sup>*</sup>
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 <sup>*</sup>	-0.12	-0.30 <sup>*</sup>	-0.61 <sup>**</sup>	-0.18	-0.39 <sup>**</sup>	-0.36 <sup>**</sup>	0.1	0.27 <sup>*</sup>
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 <sup>*</sup>	-0.19	-0.26 <sup>*</sup>	-0.60 <sup>**</sup>	-0.22	-0.42 <sup>**</sup>	-0.37 <sup>**</sup>	0.09	0.27 <sup>*</sup>
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 <sup>**</sup>	-0.26 <sup>*</sup>	-0.23	-0.59 <sup>**</sup>	-0.28 <sup>*</sup>	-0.48 <sup>**</sup>	-0.39 <sup>**</sup>	0.08	0.27 <sup>*</sup>
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 <sup>**</sup>	-0.32 <sup>*</sup>	-0.21	-0.61 <sup>**</sup>	-0.32 <sup>*</sup>	-0.48 <sup>**</sup>	-0.38 <sup>**</sup>	0.06	0.27 <sup>*</sup>
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 <sup>**</sup>	-0.37 <sup>**</sup>	-0.18	-0.61 <sup>**</sup>	-0.38 <sup>**</sup>	-0.48 <sup>**</sup>	-0.37 <sup>**</sup>	0.03	0.27 <sup>*</sup>

<sup>\*</sup>and <sup>\*\*</sup> Significant at 5% and 1% levels of significance, respectively.

<sup>#</sup>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.

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

naturally liable to some fluctuations from one season to another [14]. 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 10). 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 [14,22,33].

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 7). 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 7) 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 ( $39.1/72.9 = 0.54$ ) (14,22,33).

**Table 12:** 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 <sup>z</sup>	R <sup>2</sup>	Significance
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	**
	$Y_2 = 19.65 + 0.62X_3 - 0.25X_4 - 1.44X_7 + 0.12X_9$	0.6	**
	$Y_3 = 15.83 + 0.60X_3 - 0.22X_4 - 1.26X_7 + 0.14X_9$	0.59	**

<sup>z</sup>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<sup>-1</sup>),  $X_7$  = sunshine duration (h day<sup>-1</sup>),  $X_8$  = maximum humidity (%) and  $X_9$  = minimum humidity (%) (Sawan et al. 2005).

**Table 13:** 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 <sup>z</sup>	R <sup>2</sup>	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	**

<sup>z</sup> 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<sup>-1</sup>),  $X_6$  = soil surface temperature (°C) at 1800,  $X_7$  = sunshine duration (h day<sup>-1</sup>),  $X_8$  = maximum humidity (%) and  $X_9$  = minimum humidity (%) (Sawan et al. 2005).

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 8-11) [14] 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 12 and 13) [14].

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 12). 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 13) 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 [14]. Meanwhile, they explained a sensible proportion of the variation in flower and boll production, as indicated by their R<sup>2</sup>, which ranged between 0.14-0.62, where most of R<sup>2</sup> 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. [29] 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 ( $Y_2$ ) 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 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 [14] 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. 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 [4]. This is contradictory to the finding of Holaday et al [33]. 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 [11]. 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. [23] and Oosterhuis [30]. Also, Mergeai and Demol [27] found that cotton yield was assisted by intermediate relative humidity.

## Conclusion

Evaporation, sunshine duration, relative humidity, surface soil temperature at 1800 h and maximum temperature, were the most significant climatic factors affecting flower and boll production of Egyptian cotton. The negative correlation between each of evaporation and sunshine duration with flower and boll formation along with the positive correlation between minimum relative humidity value and flower and boll production, indicate that low evaporation rate, short period of sunshine duration and high value of minimum humidity would enhance flower and boll formation. Temperature appeared to be less important in the reproduction growth stage of cotton in Egypt than evaporation (water stress), sunshine duration and minimum humidity. 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 relative humidity were not taken into consideration in the research studies conducted by other researchers in other countries [11]. 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 possibly 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 in 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, yet only 50% of the variation in yield could be statistically explained by these factors and hence consideration should also be given to the

management practices presently in use. The 5-day interval was found to give adequate and sensible relationships between climatic factors and cotton production growth under Egyptian conditions when compared with other intervals and daily observations [15]. It may be concluded that the 5-day accumulation of climatic data during the production stage, in the absence of sharp fluctuations in these factors, could be satisfactorily used to forecast adverse effects on cotton production and the application of appropriate production practices circumvent possible production shortage.

Finally, the early prediction of possible adverse effects of climatic factors might modify their effect on production of Egyptian cotton. Minimizing deleterious effects through the application of proper management practices, such as, adequate irrigation regime, and utilization of specific plant growth regulators could limit the negative effects of some climatic factors [22,33].

## References

1. Sawan ZM. Statistical methods to evaluate the relationship between climatic factors during the development periods of flowering and boll formation and cotton production. *International Journal of Environmental Science & Natural Resources*. 2015; 1: 1-8.
2. El-Zik KM. The cotton plant - its growth and development. *Western Cotton Prod. Conf. Summary Proc.*, Fresno, CA. 1980; 18-21.
3. Guinn G. Causes of square and boll shedding in cotton. *USDA Tech. Bull.* 1672. 1982.
4. Sawan ZM. Studying the relationship between climatic factors and cotton production by different applied methods. *Journal of Stress Physiology & Biochemistry*. 2013; 9: 251-278.
5. Xiao JF, Liu ZG, Yu XG, Zhang JY, Duan AW. Effects of different water application on lint yield and fiber quality of cotton under drip irrigation. *Acta Gossypii Sinica*. 2000; 12: 194-197.
6. Barbour MM, Farquhar GD. Relative humidity and ABA-induced variation in carbon and oxygen isotope ratios of cotton leaves. *Plant, Cell and Environment*. 2000; 23: 473-485.
7. Burke JJ, Mahan JR, Hatfield JL. Crop specific thermal kinetic windows in relation to wheat and cotton biomass production. *Agron J*. 1988; 80: 553-556.
8. Hodges HF, Reddy KR, McKinion JM, Reddy VR. Temperature effects on cotton. *Bulletin Mississippi Agricultural and Forestry Experiment Station No.* 1993; 990: 15.
9. Reddy KR, Robana RR, Hodges HF, Liu XJ, Mckinion JM. Interactions of  $CO_2$  enrichment and temperature on cotton growth and leaf characteristics. *Environ Exp Bot*. 1998; 39: 117-129.
10. Schrader SM, Wise RR, Wacholtz WF, Ort DR, Sharkey TD. Thylakoid membrane responses to moderately high leaf temperature in Pima Cotton. *Plant, Cell and Environment*. 2004; 27: 725-735.
11. Sawan ZM. Climatic factors: evaporation, sunshine, relative humidity, soil and air temperature and cotton production. *Annual Research & Review in Biology*. 2014; 4: 2835-2855.
12. Zhou ZG, Meng YL, Shi Pei, Shen YQ, Jia ZK. Study of the relationship between boll weight in wheat-cotton double cropping and meteorological factors at boll-forming stage. *Acta Gossypii Sinica*. 2000; 12: 122-126.
13. Sawan ZM, Hanna LI, McCuistions WL, Foote RJ. Egyptian cotton (*Gossypium barbadense*) flower and boll production as affected by climatic factors and soil moisture status. *Theoretical and Applied Climatology*. 2010; 99: 217-227.
14. Sawan ZM, Hanna LI, McCuistions WL. Response of flower and boll development to climatic factors before and after anthesis in Egyptian cotton. *Climate Research*. 2005; 29: 167-179.

15. Sawan ZM, Hanna LI, McCuistions WL. Interval of days required for determining efficient relations between climatic factors and cotton flower and boll production. *Canadian Journal of Plant Science*. 2002; 82: 499-506.
16. Cady FB, Allen DM. Combining experiments to predict future yield data. *Agron J*. 1972. 64: 211-214.
17. Draper NR, Smith H. *Applied Regression Analysis*. John Wiley & Sons Ltd., New York, NY. 407. 1966.
18. Kaur R, Singh OS. Response of growth stages of cotton varieties to moisture stress. *Indian J Plant Physiol*. 1992; 35: 182-185.
19. Orgaz F, Mateos L, Fereres E. Season length and cultivar determine the optimum evapotranspiration deficit in cotton. *Agron J*. 1992; 84: 700-706.
20. Sawan ZM. Nature relation between climatic variables and cotton production. *Journal of Stress Physiology & Biochemistry*. 2014; 9: 251-278.
21. Bhatt JG. Growth and flowering of cotton (*Gossypium hirsutum* L.) as affected by day length and temperature. *Journal of Agricultural Science*. 1977; 89: 583-588.
22. Sawan ZM. Climatic factors; cotton production: studying its relationships by different applied statistical methods. *Journal of Statistics and Mathematical*. 2016; 2: 109-120.
23. Moseley D, Landivar JA, Locke D. Evaluation of the effect of methanol on cotton growth and yield under dry-land and irrigated conditions. In *Proceedings Belt wide Cotton Conferences*, January 5-8, San Diego, CA, USA. Memphis, USA. National Cotton Council. 1994; 1293-1294.
24. Zhao DL, Oosterhuis D. Physiological response of growth chamber-grown cotton plants to the plant growth regulator PGR-IV under water-deficit stress. *Environ Exper Botany*. 1997; 38: 7-14.
25. Meek CR, Oosterhuis DM, Steger AT. Drought tolerance and foliar sprays of glycine betaine. In *Proceedings Beltwide Cotton Conferences*, January 3-7, Orlando, FL, USA. Memphis, USA. National Cotton Council. 1999; 559-561.
26. Reddy KR, Hodges HF, McKinion JM. Can cotton crops be sustained in future climates? *Proceeding Belt wide Cotton Conferences*. January 9-12, Memphis, USA; National Cotton Council, TN, Nashville, TN, USA. 1996; 1189-1196.
27. Mergeai G, Demol J. Contribution to the study of the effect of various meteorological factors on production and quality of cotton (*Gossypium hirsutum* L.) fibers. *Bulletin des Recherches Agronomiques de Gembloux*. 1991; 26: 113-124.
28. Ward DA, Bunce JA. Responses of net photosynthesis and conductance to independent changes in the humidity environments of the upper and lower surfaces of leaves of sunflower and soybean. *J Exper Botany*. 1986; 37: 1842-1853.
29. Miller JK, Krieg DR, Paterson RE. Relationship between dryland cotton yields and weather parameters on the Southern Hig Plains. In *Proceedings Belt wide Cotton Conferences*, January 9-12, Nashville, TN, USA, Memphis, USA, National Cotton Council. 1996; 1165-1166.
30. Oosterhuis DM. Effect of temperature extremes on cotton yields in Arkansas. In *Proceedings of the Cotton Research Meeting*, held at Monticello, Arkansas, USA, February 13 [Edited by Oosterhuis, D.M.; Stewart, J.M.]. *Special Report-Agricultural Experiment Station, Division of Agriculture, University of Arkansas*, No. 1997; 183: 94-98.
31. Boyer JS, Johnson RR, Saupe SG. Afternoon water deficits and grain yields in old and new soybean cultivars. *Agron J*. 1980; 72: 981-986.
32. Human JJ, Du Toit D, Bezuidenhout HD, De Bruyn LP. The influence of plant water stress on net photosynthesis and yield of sunflower (*Helianthus annuus* L.). *J Agron Crop Sci*. 1990; 164: 231-241.
33. Holaday AS, Haigler CH, Srinivas NG, Martin LK, Taylor JG (1997) Alterations of leaf photosynthesis and fiber cellulose synthesis by cool night temperatures. In *Proceedings. Beltwide Cotton Conferences*, January 6-10, New Orleans. National Cotton Council, Memphis, TN, 1997; 1435-1436.
34. Sawan ZM. Different applied mathematics and statistics methods to evaluate the response of cotton production to climatic variables. *Elixir International Journal, Elixir Statistics*. 2016; 92: 39348-39364.