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# Different Applied Statistical Methods to Evaluate the Response of Cotton Production to Climatic Variables

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**ABSTRACT**

This study investigates the predicted effects of climatic factors during convenient intervals (in days) on cotton flower and boll production compared with daily observations. Also, covers the statistical relationship between climatic variables and aspects of cotton production and the effects of climatic factors prevailing prior to flowering or subsequent to boll setting on flower and boll production and retention in cotton. Further, cotton flower and boll production as affected by climatic factors and soil moisture status has been considered. 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. The least important variables were found to be surface soil temperature at 0600 h and minimum temperature. The five-day interval was found to be more adequately and sensibly related to yield parameters. 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. The soil moisture status showed low and insignificant correlation with flower and boll production. Higher minimum relative humidity, short period of sunshine duration, and low temperatures enhanced flower and boll formation.



## Introduction

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 (Hodges et al. 1993).

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 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. (1988) 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.

Reddy et al. (1995) in growth chamber experiments found that Pima cotton cv. S-6 produced lower total biomass at 35.5°C than at 26.9°C and no bolls were produced at the higher temperature of 40°C. Schrader et al. (2004) stated that high temperatures that plants are likely to experience inhibit photosynthesis. 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 Texas, Guo et al. (1994) found that plant growth and yield of the cotton cv. DPL-50 (Upland cotton) were less in a humid area than in an arid area with low humidity. Under arid conditions, high vapor pressure deficit resulted in a high transpiration rates, low leaf water potential and lower leaf temperatures.

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Fisher (1975) found that high temperatures can cause male sterility in cotton flowers, and could have caused increased boll shedding in the late fruiting season. Zhao (1981) indicated that temperature was the main climatic factor affecting cotton production and 20-30°C was the optimum temperature for cotton growth.

Hodges et al. (1993) 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. (1998) 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.

The objectives of this study were: A- 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 (Sawan et al. 2006). B- 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 boll 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 (Sawan et al. 2005). And C-, 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 (Sawan et al. 2010).

**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 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) (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-m³ $h^{-1}$. 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 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 (Sawan et al. 2010).

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$^{th}$ 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 (Sawan et al. 2010).

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).

**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), ($X_1$) | 31.0-44.0 | 34.3 | 30.6-38.8 | 34.1 | 30.6-44.0 | 34.2 |
| Min Temp (°C), ($X_2$) | 18.6-24.5 | 21.9 | 18.4-23.9 | 21.8 | 18.4-24.5 | 21.8 |
| Max-Min Temp (°C), ($X_3$)♦ | 9.4-20.9 | 12.4 | 8.5-17.6 | 12.2 | 8.5-20.9 | 12.3 |
| Evap (mm $d^{-1}$), ($X_4$) | 7.6-15.2 | 10.0 | 4.1-9.8 | 6.0 | 4.1-15.2 | 8.0 |
| 0600 h Temp (°C), ($X_5$) | 14.0-21.5 | 17.8 | 13.3-22.4 | 18.0 | 13.3-22.4 | 17.9 |
| 1800 h Temp (°C), ($X_6$) | 19.6-27.0 | 24.0 | 20.6-27.4 | 24.2 | 19.6-27.4 | 24.1 |
| Sunshine (h $d^{-1}$), ($X_7$) | 10.3-12.9 | 11.7 | 9.7-13.0 | 11.9 | 9.7-13.0 | 11.8 |
| Max RH (%), ($X_8$) | 62-96 | 85.4 | 51-84 | 73.2 | 51-96 | 79.6 |
| Min RH (%), ($X_9$) | 11-45 | 30.8 | 23-52 | 39.8 | 11-52 | 35.1 |
| Wind speed (m $s^{-1}$), ($X_{10}$) | ND | ND | 2.2-7.8 | 4.6 | ND | ND |

(Sawan et al. 2006).

♦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).

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 (Sawan et al. 2005). Range and mean values of the climatic parameters recorded during the production stage for both seasons and overall data are listed in Table 1 (Sawan et al. 2006). 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. 2005).

**Figure legends**


**Figure 1**

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).

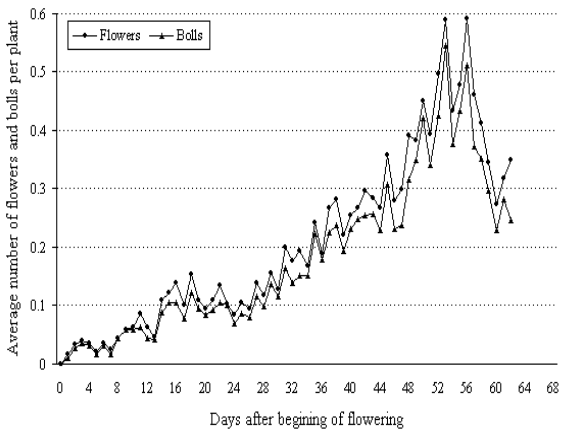


**Figure 2**

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).

**Results and Discussion**

**A- 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 each season. Comparisons between the values of “r” were done to determine the best interval of days for determining effective relationships. The α-level for significance was $P \leq 0.15$. 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 (Cady and Allen 1972). 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 (1966) (Sawan et al. 2006).

***Correlation estimates***

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 2) (Sawan et al. 2006).

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 flower and boll production. High evaporation rates could result in water stress that would slow growth and increase shedding rate of flowers and bolls (Sawan et al. 2006). Kaur and Singh (1992) found in cotton that flower number was decreased by water stress, particularly when existing at flowering stage. Seed cotton yield was decreased by about 50% when water stress was present at flowering stage, slightly decreased by stress at boll formation stage, and not significantly affected by stress in the vegetative stage (6-7 weeks after sowing).

The second most important climatic factor was minimum 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 (Sawan et al. 2006).

The third most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with flower and boll production only (Sawan et al. 2006). The negative relationship between sunshine duration and cotton production may be due to the fact that the species of the genus *Gossypium* are known to be short day plants (Hearn and Constable 1984), so, an increase of sunshine duration above that sufficient to attain good plant growth will decrease flower and boll production. Bhatt (1977) found that exposure to daylight over 14 hours 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, yet it could reach 13 h, which, in combination with high maximum temperatures (up to 38.8°C), may have adversely affected reproductive growth.

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 (Sawan et al. 2006).

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 (Sawan et al. 2006). 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. In this connection, Meek et al. (1999) in a field experiment in Arkansas found that application of 3 or 6 kg glycine betaine (PGR) $ha^{-1}$ to cotton plants under mild water stress increased yield.

Comparing results for the different intervals of days with those from daily observation (Table 2) (Sawan et al. 2006), 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 $R^2$ 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 (Sawan et al. 2006).

***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 ($Y_1$); bolls per plant ($Y_2$); and boll retention ratio ($Y_3$)] and the studied climatic factors (Table 3) (Sawan et al. 2006).

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 $R^2$ 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) (Sawan et al. 2006).

The $R^2$ 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 (Sawan et al. 2006).

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.

**Table 2. 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 | Climatic factors[z] Air temp (°C) Max ($X_1$) | Min ($X_2$) | Max-Min($X_3$) | Evap (mm d$^{-1}$) ($X_4$) | Surface soil temp (°C) 0600 h ($X_5$) | 1800 h ($X_6$) | Sunshine duration (h d$^{-1}$) ($X_7$) | Relative humidity (%) Max ($X_8$) | Min ($X_9$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 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 ($n^{\#}$ = 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 ($n^{\#}$ = 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 ($n^{\#}$ = 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 ($n^{\#}$ = 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 ($n^{\#}$ = 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 ($n^{\#}$ = 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 | $0.55^{*}$ |

(Sawan et al. 2006).

[z] 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.

# n = Number of data pairs used in calculation.

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 (Sawan et al. 2006).

**B- 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 (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 4) (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. The following is an example (in the first season):

| File | Data of any dependent variable (for each flowers and bolls) Production stage | | Any independent variable (for each climatic factors) 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<br>68 | 23 Jun-29 Aug | 68<br>68 | 23 Jun-29 Aug | 68<br>68 |
| 1st new file | 23 Jun-29 Aug | 68<br>68 | 22 Jun-28 Aug | 68<br>68 | 24 Jun-30 Aug | 68<br>68 |
| 2nd new file | 23 Jun-29 Aug | | 21 Jun-27 Aug | | 25 Jun-31 Aug | |
| 15th new file | 23 Jun-29 Aug | | 8 Jun-14 Aug | | 8 Jul - 13 Sept | |

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).

***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 5 and 6) revealed the following (Sawan et al. 2005):

**Table 3. The equations obtained for each of the studied cotton production variables for the five-day intervals and daily intervals combined over both seasons**

| Equation [z] | $R^2$ | Significance |
|---|---|---|
| **Five-day intervals** | | |
| $Y_1 = 23.78 – 0.5362X_4 – 0.1429X_6 – 0.1654X_7 + 0.0613X_9$ | 0.6237 | ** |
| $Y_2 = 15.89 – 0.4762X_4 – 0.1583X_6 – 0.1141X_7 + 0.0634X_9$ | 0.5945 | ** |
| $Y_3 = 72.65 – 0.0833X_4 – 0.1647X_6 + 0.2278X_9$ | 0.6126 | ** |
| **Daily intervals** | | |
| $Y_1 = 19.78 – 0.181X_3 – 0.069X_4 – 0.164X_6 – 0.182X_7 + 0.010X_9$ | 0.4117 | ** |
| $Y_2 = 14.96 – 0.173X_3 – 0.075X_4 – 0.176X_6 – 0.129X_7 + 0.098X_9$ | 0.4461 | ** |
| $Y_3 = 52.36 – 3.601X_4 – 0.2352X_7 + 4.511X_9$ | 0.3587 | ** |

(Sawan et al. 2006).

[z]Where $Y_1$ = number of flowers per plant, $Y_2$ = number of bolls per plant, $Y_3$ = boll retention ratio, $X_3$ = maximum – minimum temperature °C, $X_4$ = evaporation mm day$^{-1}$, $X_6$ = surface soil temperature °C at 1800 h., $X_7$ = sunshine duration h day$^{-1}$, and $X_9$ = minimum relative humidity %.

**Table 4. 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-Mintemp [°C] ($X_3$)♦ | 12.6 | 1.1 | 20.9 | 9.4 | 12.4 | 1.3 | 17.6 | 8.5 |
| Evapor [mm d$^{-1}$] | 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)

***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 5). 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 5). 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 (Sawan et al. 2005).

***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 6) (Sawan et al. 2005).

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 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-afternoon photosynthetic rates even under well-watered conditions.

***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 7 and 8) (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 7) (Sawan et al. 2005). Meanwhile its relationship with retention ratio was positive and significant in the 9-15 day periods after flowering.

**Table 5. 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) Max. | Air temp. (°C) Min. | Air temp. (°C) Max-Min[♦] | Evap. (mm d$^{-1}$) | Surface soil temp. (°C) 0600 h | Surface soil temp. (°C) 1800 h | Sunshine duration (h d$^{-1}$) | Humidity (%) Max. | Humidity (%) Min. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | ($X_1$) | ($X_2$) | ($X_3$) | ($X_4$) | ($X_5$) | ($X_6$) | ($X_7$) | ($X_8$) | ($X_9$) |
| 0[#] | Flower | -0.07 | -0.06 | -0.03 | -0.56** | -0.01 | -0.20 | -0.25* | 0.40** | 0.14 |
| | Boll | -0.03 | -0.07 | -0.01 | -0.53** | -0.06 | -0.16 | -0.14 | 0.37** | 0.10 |
| 1 | Flower | -0.15 | -0.08 | -0.11 | -0.64** | -0.01 | -0.17 | -0.30* | 0.39** | 0.20 |
| | Boll | -0.07 | -0.08 | -0.02 | -0.58** | -0.06 | -0.10 | -0.23* | 0.36** | 0.13 |
| 2 | Flower | -0.26* | -0.10 | -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** | 0.20 |
| 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 | -0.20 | -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 | 0.00 | -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** | 0.10 | -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 | -0.10 | -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 | -0.20 | 0.10 | -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 | 0.00 | 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 | 0.00 | 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 | -0.10 | -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 ti

**Table 6. Simple correlation coefficients (r) between climatic factors[z] 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) Max. ($X_1$) | Air temp. (°C) Min. ($X_2$) | Air temp. (°C) Max-Min[♦] ($X_3$) | Evap. (mm $d^{-1}$) ($X_4$) | Surface soil temp. (°C) 0600 h ($X_5$) | Surface soil temp. (°C) 1800 h ($X_6$) | Sunshine duration (h $d^{-1}$) ($X_7$) | Humidity (%) Max. ($X_8$) | Humidity (%) Min. ($X_9$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0[#] | Flower | -0.42** | 0.00 | -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** | 0.10 | -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** | 0.00 | 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** | 0.00 | -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** | 0.10 | -0.02 | -0.31** | 0.08 | 0.32** |
| | Boll | -0.15 | 0.29* | -0.26* | -0.53** | 0.10 | 0.00 | -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* | 0.10 | 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 | -0.20 | 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).

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 8) (Sawan et al. 2005). 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 (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 $mm.d^{-1}$ 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 (Sawan et al. 2005). 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. 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 7). 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).

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 (Sawan et al. 2005). 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 4). 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 4) 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) (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 5-8) (Sawan et al. 2005) 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 9 and 10) (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 9) (Sawan et al. 2005). 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 10) (Sawan et al. 2005) indicated that evaporation was the most effective and consistent climatic

**Table 7. 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) Max. ($X_1$) | Min. ($X_2$) | Max.-Min♦. ($X_3$) | Evap. (mm $d^{-1}$) ($X_4$) | Surface soil temp. (°C) 0600 h ($X_5$) | 1800 h ($X_6$) | Sunshine duration (h $d^{-1}$) ($X_7$) | Humidity (%) Max. ($X_8$) | Min. ($X_9$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0# | Retention ratio• | -0.05 | -0.03 | -0.03 | -0.10 | -0.11 | 0.10 | 0.20 | -0.04 | -0.02 |
| | No. of bolls | -0.03 | -0.07 | -0.01 | -0.53** | -0.06 | -0.16 | -0.14 | 0.37** | 0.10 |
| 1 | Retention ratio | -0.07 | -0.08 | -0.01 | -0.10 | -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 | -0.20 | 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 | -0.10 |
| | 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 | -0.20 | 0.09 | -0.01 | -0.24* | 0.01 | 0.22 | 0.00 | -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* | 0.00 | 0.26* | -0.02 | -0.22 |
| | No. of bolls | 0.00 | -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 | -0.20 |
| | 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 | -0.20 | 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 | 0.00 | 0.08 | 0.26* | -0.14 | 0.08 | 0.29* | -0.12 | -0.20 |
| | No. of bolls | -0.08 | -0.06 | -0.05 | -0.33** | -0.01 | 0.00 | -0.23 | 0.20 | 0.16 |
| 10 | Retention ratio | 0.06 | -0.02 | 0.05 | 0.27* | -0.13 | 0.09 | 0.27* | -0.10 | -0.08 |
| | No. of bolls | -0.11 | -0.10 | -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** | -0.10 | -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** | 0.00 | 0.01 | 0.27* | -0.09 | -0.02 |
| | No. of bolls | -0.15 | -0.09 | -0.09 | -0.29* | -0.03 | -0.10 | -0.08 | 0.18 | 0.20 |
| 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 | -0.10 | -0.10 | -0.28* | -0.01 | -0.10 | -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 | 0.00 |
| | 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).

**Table 8. 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. ($mm\ d^{-1}$) | Surface soil temp. (°C) | | Sunshine duration ($h\ d^{-1}$) | Humidity (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Max. | Min. | Max.-Min[♦] | | 0600 h | 1800 h | | Max. | Min. |
| | | ($X_1$) | ($X_2$) | ($X_3$) | ($X_4$) | ($X_5$) | ($X_6$) | ($X_7$) | ($X_8$) | ($X_9$) |
| 0[#] | Retention ratio• | -0.04 | 0.20 | -0.31* | -0.14 | 0.12 | -0.20 | 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 | -0.10 | -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 | -0.10 | -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 | -0.10 | 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 | 0.00 | -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 | -0.10 | -0.11 | -0.01 | -0.04 | -0.03 | 0.02 |
| | No. of bolls | -0.15 | -0.02 | -0.19 | -0.60** | -0.10 | -0.29* | -0.32* | 0.10 | 0.18 |
| 8 | Retention ratio | -0.02 | 0.05 | 0.03 | -0.10 | -0.04 | -0.03 | -0.02 | -0.01 | 0.01 |
| | No. of bolls | -0.20 | -0.03 | -0.23 | -0.61** | -0.10 | -0.28* | -0.32* | 0.19 | 0.22 |
| 9 | Retention ratio | -0.02 | 0.13 | -0.05 | -0.10 | 0.08 | -0.05 | -0.01 | 0.03 | 0.00 |
| | 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 | 0.10 | -0.10 | -0.08 | 0.03 | 0.20 | -0.03 | 0.05 | 0.04 |
| | No. of bolls | -0.30* | -0.12 | -0.30* | -0.61** | -0.18 | -0.39** | -0.36** | 0.10 | 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 | -0.10 | -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.

factor affecting number of harvested bolls.

**Table 9. 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)**

| SeasonModel [z] | $R^2$ | 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 | ** |
| $Y_2 = 19.65 + 0.62X_3 – 0.25X_4 – 1.44X_7 + 0.12X_9$ | 0.60 | ** |
| $Y_3 = 15.83 + 0.60X_3 – 0.22X_4 – 1.26X_7 + 0.14X_9$ | 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).

Regression models obtained demonstrate of each independent variable under study as an efficient and important factor. 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 (Sawan et al. 2005).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 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 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 (Sawan et al. 2005). Various activities have been suggested to partially overcome water stress.

**Table 10. 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. Sunshine duration and minimum humidity appeared to have secondary effects, yet they are in fact important players (Sawan et al. 2005). 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.

**C- 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 ($Y_2$) (Sawan et al. 2010).

B. Independent variables (Xs) (Sawan et al. 2010):

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).
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 ≤ 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 (1972). 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 (1985) using the procedures outlined in the general linear model (GLM) (SAS Institute 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 11-13 (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 (Sawan et al. 2010). 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).

**Table 11. 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 |
| (X13) Largest maxRH [%] on days 7-12 | 0.4499[a] | 0.3554[b] |
| (X14) Lowest minRH [%] on days 7-12 | 0.3522[a] | 0.1937[d] |
| (X15) Lowest minRH [%] on days 50-52 | -0.3440[a] | -0.4222[a] |
| (X16) Daily light period (hour) | -0.2430[b] | -0.1426 |

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

**Table 12. 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] |

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

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).

**Table 13. Simple correlation coefficient (r) values between the independent variables and dependent variables in the combined two seasons (I and II)**

| 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] |

(Sawan et al. 2010).

[a] Significant at 1 % probability level
[b] Significant at 5 % probability level
[c] Significant at 10 % probability level
[d] Significant at 15 % probability level

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 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 37.5 °C (X4) and minRH did not show significant relations in the first season, while that trend differed in the second season (Sawan et al. 2010).

These results indicated that relative humidity was the most effective and consistent climatic factor affecting boll production (Sawan et al. 2010). Moseley et al. (1994) stated that methanol has been reported to increase water use efficiency, growth and development of $C_3$ plants in arid conditions, under intense sunlight. In field trials cotton cv. DPL-50 (*Gossypium hirsutum*), was sprayed with a nutrient solution (1.33 lb N + 0.27 lb Fe + 0.27 lb Zn $acre^{-1}$) or 30% methanol solution at a rate of 20 gallons $acre^{-1}$, or sprayed with both the nutrient solution and methanol under two soil moisture regimes (irrigated and dry land).

The second most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with boll production (Sawan et al. 2010).

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 and 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.

***C-2. 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 14).

**Table 14. Model obtained for cotton production variables as functions of climatic data and soil moisture status in individual and combined seasons. All entries significant at 1% level**

| 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 |

(Sawan et al. 2010).

(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).

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 (Sawan et al. 2010).

Relative humidity showed the highest contribution to the variation in both flower and boll production (Table 14). 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. Warner and Burke (1993) indicated that the cool-night inhibition of cotton (*Gossypium hirsutum*) growth is correlated with biochemical limitation on starch mobilization in source leaves, which result in a secondary inhibition of photosynthesis, even under optimal temperature during the day. 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 (Sawan et al. 2010). 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 2013).

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 (Sawan et al. 2010). This is contradictory to the finding of Holaday et al. (1997). 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 (Sawan 2014a). Sunshine duration and minimum relative humidity appeared to have secondary effects, yet they are in fact important factors.

**Conclusions**

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. Also, it could be concluded that during the 15-day periods both prior to and after initiation of individual boll, evaporation, minimum relative humidity and sunshine duration, were the most significant climatic factors affecting cotton flower and boll production and retention in 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 (Sawan et al. 2005). 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 (Sawan 2014b). 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 (Sawan et al. 2006). 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. Evaporation and sunshine duration appeared to be important climatic factors affecting boll production in Egyptian cotton. Our findings indicate that increasing evaporation rate and sunshine duration resulted in lower boll production. On the other hand, relative humidity, which had a positive correlation with boll production, was also an important climatic factor. In general, increased relative humidity would bring about better boll production. Temperature appeared to be less important in the reproduction growth stage of cotton in Egypt than minRH (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 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.

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 (Sawan 2010).

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