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Climatic Factors; Cotton Production: Studying its Relationships by Different Applied Statistical Methods

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ABSTRACT

The study investigated the effect of various climatic factors on flower and boll production and retention in cotton. Also, investigated the relationship between climatic factors and production of flowers and bolls obtained during the development periods of the flowering and boll stage, and to determine the most representative period corresponding to the overall crop pattern. Evaporation, sunshine duration, relative humidity, surface soil temperature at 18:00 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 06:00 h and minimum temperature. 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. Higher minimum relative humidity, short period of sunshine duration, and low temperatures enhanced flower and boll formation.

INTRODUCTION

Cotton yield is a function of growth rates; flower production rates; and flower and boll retention during the fruiting period. Information on the relationship between climatic factors and the cotton plant's ability to produce and sustain flower buds; flowers; and bolls will allow one to model plant responses to conditions that frequently occur in the field and to predict developmental rate or the formation of these organs. 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 [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] 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. [8] 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. Gutiérrez and López [9] studied the effects of heat on the yield of cotton in Andalucia; Spain; during 1991-1998; 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. Schrader et al. [10] stated that high temperatures that plants are likely to experience inhibit photosynthesis. Wise et al. [11] 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°C - 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. 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 [12].

Zhou et al. [13] 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- The effect of various climatic factors on the overall flower and boll production in Egyptian cotton. This could pave the way for formulating advanced predictions as for the effect of certain climatic conditions on cotton 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 increase in cotton yield. B- Also; this study investigated the relationship between climatic factors and production of flowers and bolls obtained during the development periods of the flowering and boll stage; and to determine the most representative period corresponding to the overall crop pattern. 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 [12].

DATA AND METHODS

Two uniform field trials were conducted at the experimental farm of the Agricultural Research Center; Ministry of Agriculture; Giza; Egypt (30ºN; 31º: 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) [14].

In Egypt; there are no rain-fed areas for cultivating cotton. Water for the field trials was applied using surface irrigation. Total water consumed during each of two growing seasons supplied by surface irrigation was about 6;000-m^3 h^{-1}. The criteria used to determine amount of water applied to the crop depended on soil water status. Irrigation was applied when soil water content reached about 35% of field capacity (0-60 cm). In season I; the field was irrigated on 15 March (at planting); 8 April (first irrigation); 29 April; 17 May; 31 May; 14 June; 1 July; 16 July; and 12 August. In season II; the field was irrigated on 23 March (planting date); 20 April (first irrigation); 8 May; 22 May; 1 June; 18 June; 3 July; 20 July; 7 August and 28 August. Techniques normally used for growing cotton in Egypt were followed. Each experimental plot contained 13 to 15 ridges to facilitate proper surface irrigation. Ridge width was 60 cm and length was 4 m. Seeds were sown on 15 and 23 March in seasons I and II; respectively; in hills 20 cm apart on one side of the ridge. Seedlings were thinned to 2 plants per hill 6 weeks after planting; resulting in a plant density of about 166;000 plants ha^{-1}. Phosphorus fertilizer was applied at a rate of 54 kg P_2O_5 ha^{-1} as calcium super phosphate during land preparation. Potassium fertilizer was applied at a rate of 57 kg K_2O ha^{-1} as potassium sulfate before the first irrigation (as a concentrated band close to the seed ridge). Nitrogen fertilizer was applied at a rate of 144 kg N ha^{-1} as ammonium nitrate in two equal doses: the first was applied after thinning just before the second irrigation and the second was applied before the third irrigation. Rates of phosphorus; potassium; and nitrogen fertilizer were the same in both seasons. These amounts were determined based on the use of soil tests [14].

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 [14].

Flowers on all selected plants were tagged in order to count and record the number of open flowers; and set bolls on a daily basis. The flowering season commenced on the date of the first flower appearance and continued until the end of flowering season (31 August). The period of whole September (30 days) until the 20th of October (harvest date) allowed a minimum of 50 days to develop mature bolls. In season I; the flowering period extended from 17 June to 31 August; whereas in season II; the flowering period was from 21 June to 31 August. Flowers produced after 31 August were not expected to form sound harvestable bolls; and therefore were not taken into account [14].

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 [14].

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 (max RH) (%; X_8); minimum relative humidity (min RH) (%; 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 season's irrigation [15].

Daily records of the climatic factors (independent variables); were taken for each day during production stage in any season including two additional periods of 15 days preceding and after the production stage. Range and mean values of the climatic parameters recorded during the production stage for both seasons and overall data are listed in **Table 1.** Daily number of flowers and number of bolls per plant which survived till maturity (dependent variables) during the production stage in the two seasons are graphically illustrated in **Figures 1 and 2.**

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	4.1-9.8	6	4.1-15.2	8
0600 h Temp (°C), (X_5)	14.0-21.5	17.8	13.3-22.4	18	13.3-22.4	17.9
1800 h Temp (°C), (X_6)	19.6-27.0	24	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)	Nov-45	30.8	23-52	39.8	Nov-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)

RESULTS AND DISCUSSION

A- Response of flower and boll development to climatic factors on the anthesis day

Daily number of flowers and number of bolls per plant which survived to maturity (dependent variables) during the production stage of the two seasons (68 days and 62 days in the first and the second seasons; respectively) are graphically illustrated in **Figures 1 and 2.** The flower- and boll-curves reached their peaks during the middle two weeks of August; and then descended steadily till the end of the season. Specific differences in the shape of these curves in the two seasons may be due to the growth-reactions of environment; where climatic factors **(Table 1)** represent an important part of the environmental effects [16].

A.1. Correlation estimates: Results of correlation coefficients [correlation and regression analyses were computed; according to Draper and Smith [17] by means of the computer program SAS package 1985. Between the initial group of independent variables and each of flower and boll production in the first and second seasons and the combined data of the two seasons are shown in **Table 2** [1].

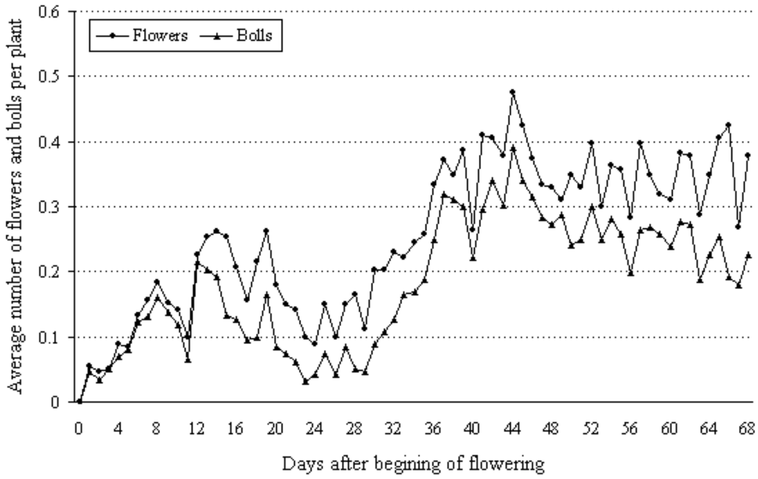

Figure 1. Daily number of flowers and bolls during the production stage (68 days) in the first season (I) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E), Egypt. The soil 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).

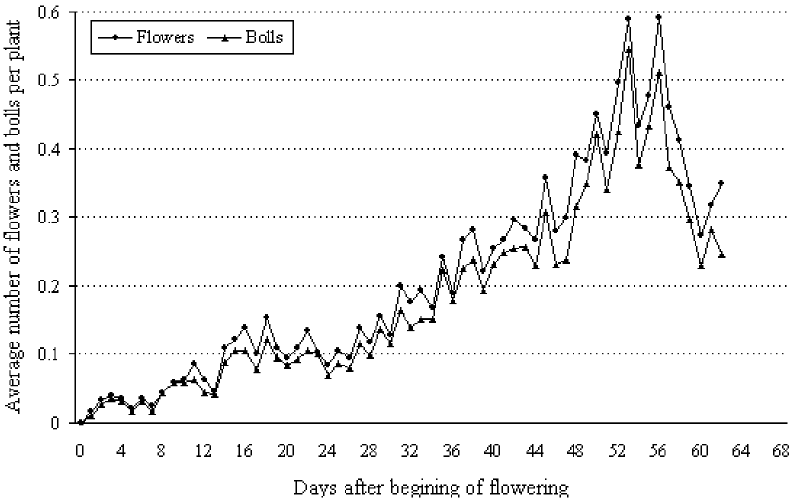

Figure 2. Daily number of flowers and bolls during the production stage (62 days) in the second season (II) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E), Egypt. The 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).

The correlation values indicate clearly that evaporation is the most important climatic factor affecting flower and boll production as it showed the highest correlation value. This factor had a significant negative relationship with flower and boll production. Sunshine duration showed a significant negative relation with fruit production except for boll production in the first season; which was not significant. Maximum air temperature; temperature magnitude; and surface soil temperature at 1800 h; were also negatively correlated with flower and boll production in the second season and the combined data of the two seasons. Minimum humidity in the second season; the combined data of the two seasons; and maximum humidity in the first season were positively and highly correlated with flower and boll production. Minimum air temperature and soil surface temperature at 0600 h showed low and insignificant correlation to flower and boll production [1].

The negative relationship between evaporation with flower and boll production; means that high evaporation rate significantly reduces cotton flower and boll production. This may be due to greater plant water deficits when evaporation increases. Also; the negative relation between each of maximum temperature; temperature magnitude; surface soil temperature at 1800 h; or sunshine duration; with flower and boll production revealed that the increase in the values of these factors had a detrimental effect upon fruit production in Egyptian cotton. On the other hand; there was a positive correlation between each of maximum or minimum humidity with flower and boll production.

Results obtained from the production stage of each season individually; and the combined data of the two seasons; indicate that relationships of some climatic variables with the dependent variables varied markedly from one season to another. 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; minimum humidity and soil surface temperature at 1800 h did not show significant relations in the first season; while that trend differed in the second season. The 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 mean values of this factor in the two seasons; where it was; on average; about 86% in the first season; and about 72% on average in the second season; as shown in **Table 1** [18].

Boll retention ratio [(The number of retained bolls obtained from the total number of each daily tagged flowers in all selected plants at harvest/Total number of daily tagged flowers of all selected plants) x 100] curves for both of the two seasons are shown in **Figures 3 and 4** [1].

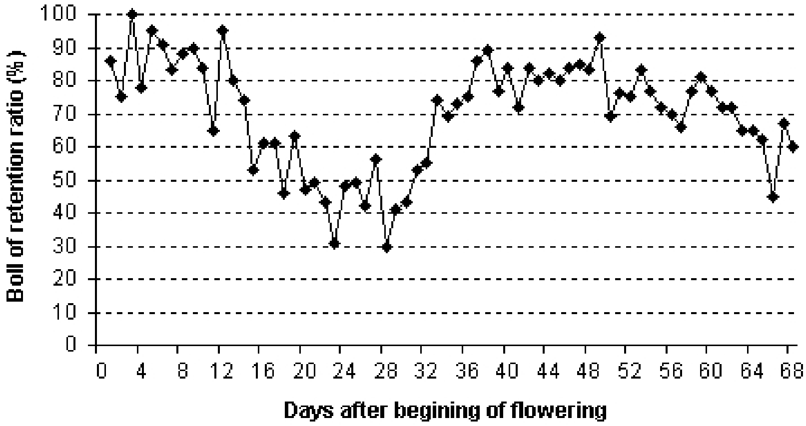

Figure 3. Daily boll retention ratio during the production stage (68 days) in the first season (I) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E at an altitude 19 m), 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^3 ha^{-1}. No rainfall occurred during the growing season. The sampling size was 261 plants (Sawan et al. 2002).

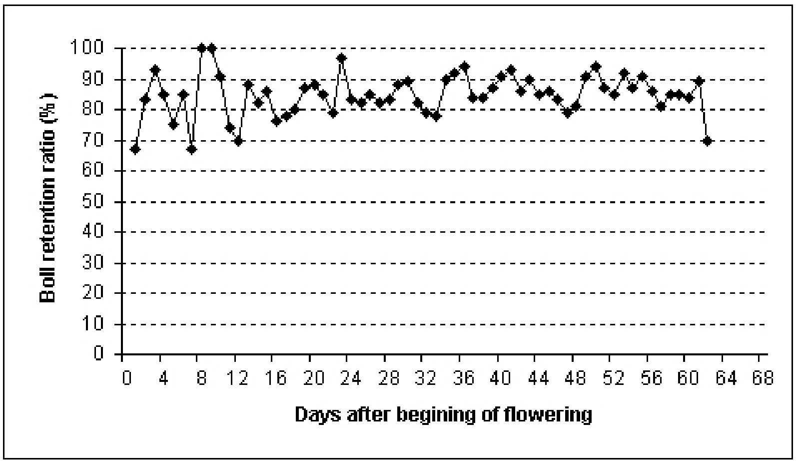

Figure 4. Daily boll retention ratio during the production stage (62 days) in the second (II) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E at an altitude 19 m), Egypt. 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^3 ha^{-1}. No rainfall occurred during the growing season. The sampling size was 358 plants (Sawan et al. 2002).

These results indicate that evaporation is the most effective and consistent climatic factor affecting boll production. As the sign of the relationship was negative; this means that an increase in evaporation would cause a significant reduction in boll number. Thus; applying specific treatments such as an additional irrigation; and use of plant growth regulators; would decrease the deleterious effect of evaporation after boll formation and hence contribute to an increase in cotton boll production and retention; and the consequence is an increase in cotton yield [1]. In this connection; Moseley et al. [19] 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 foliar spray treatments were applied 6 times during the growing season beginning at first bloom. They found that irrigation (a total of 4.5 inches applied in July) increased lint yield across foliar spray treatments by 18%. Zhao and Oosterhuis [20] reported that in a growth chamber when cotton (*Gossypium hirsutum* cv. Stoneville 506) plants were treated with the plant growth regulator PGR-IV (gibberellic acid; IBA and a proprietary fermentation broth) under water deficit stress and found significantly higher dry weights of roots and floral buds than the untreated water-stressed plants. They concluded that PGR-IV can partially alleviate the detrimental effects of water stress on photosynthesis and dry matter accumulation and improves the growth and nutrient absorption of growth chamber-grown cotton plants. Meek et al. [21] in a field experiment in Arkansas found that application of 3 or 6 kg glycine betaine (PGR) ha^{-1}; to cotton plants had the potential for increasing yield in cotton exposed to mild water stress.

A.2. Multiple linear regression equation: By means of the multiple linear regression analysis; fitting predictive equations (having good fit) were computed for flower and boll production per plant using selected significant factors from the nine climatic variables studied in this investigation. Wind speed evaluated during the second season had no influence on the dependent variables. The equations obtained for each of the two dependent variables; i.e. number of flowers (Y_1) and bolls per plant (Y_2) in each season and for combined data from the two seasons **(Table 2)** [1] are as follows:

Table 2. Simple correlation values for the relationships between the independent variables and the studied dependent variable.

Independent variables	Dependent variable					
(Climatic factors)	First season		Second season		Combined data	
	Flower	Boll	Flower	Boll	Flower	Boll
Max Temp [°C] (X_1)	–0.07	–0.03	–0.42**	–0.42**	–0.27**	–0.26**
Min Temp [°C] (X_2)	–0.06	–0.07	0	0.02	–0.03	–0.02
Max-Min Temp [°C] (X_3)	–0.03	–0.01	–0.36**	–0.37**	–0.25**	–0.24**
Evapor [mm d^{-1}] (X_4)	–0.56**	–0.53**	–0.61**	–0.59**	–0.40**	–0.48**
0600 h Temp [°C] (X_5)	–0.01	–0.06	–0.14	–0.13	–0.09	–0.09
1800 h Temp [°C] (X_6)	–0.02	–0.16	–0.37**	–0.36**	–0.27**	–0.25**
Sunshine [h d^{-1}] (X_7)	–0.25*	–0.14	–0.37**	–0.36**	–0,31**	–0.25**
Max RH [%] (X_8)	0.40**	0.37**	0.01	0.01	0.04	–0.06
Min RH [%] (X_9)	0.14	0.1	0.45**	0.46**	0.33**	0.39**
Wind speed [m s^{-1}] (X_{10})	ND	ND	–0.06	–0.04	ND	ND
(Sawan et al., 2002). ND: not determined *P < 0.05; **P < 0.01.						

First Season: (n = 68)

Y_1 = 21.691 - 1.968 X_4 - 0.241 X_7 + 0.216 X_8; R = 0.608** and R^2 = 0.3697;

While R^2 for all studied variables was 0.4022.

Y_2 = 15.434 - 1.633 X_4 + 0.159 X_8; R = 0.589** and R^2 = 0.3469 and R^2 for all studied variables was 0.3843.

Second Season: (n = 62)

Y_1 = 77.436 - 0.163 X_1 - 2.861 X_4 - 1.178 X_7 + 0.269 X_9; R = 0.644**; R^2 = 0.4147.

Y_2 = 66.281 - 0.227X_1 - 3.315X_4 - 2.897X_7 + 0.196X_9; R = 0.629**; R^2 = 0.3956.

In addition; R^2 for all studied variables was 0.4503 and 0.4287 for Y_1 and Y_2 equations respectively.

Combined data for the two seasons: (n = 130)

Y_1 = 68.143 - 0.827 X_4 - 1.190 X_6 - 2.718 X_7 + 0.512 X_9; R = 0.613**; R^2 = 0.3758

Y_2 = 52.785 - 0.997 X_4 - 0.836 X_6 - 1.675 X_7 + 0.426 X_9; R = 0.569**; R^2 = 0.3552

While R^2 for all studied variables was 0.4073 for Y_1 and 0.3790 for Y_2.

Three climatic factors; i.e. minimum air temperature; surface soil temperature at 0600 h; and wind speed were not included in the equations since they had very little effect on production of cotton flowers and bolls. The sign of the partial regression coefficient for an independent variable (climatic factor) indicates its effect on the production value of the dependent variable (flowers or bolls). This means that high rates of humidity and/or low values of evaporation will increase fruit production.

A.3. Contribution of selected climatic factors to variations in the dependent variable: Relative contributions (RC %) for each of the selected climatic factors to variation in flower and boll production is summarized in **Table 3.** Results in this table indicate that evaporation was the most important climatic factor affecting flower and boll production in Egyptian cotton. Sunshine duration is the second climatic factor of importance affecting production of flowers and bolls. Relative humidity and temperature at 1800 h were factors of lower contribution than evaporation and sunshine duration/day. Maximum temperature made a contribution less than the other affecting factors [1].

Table 3. Selected factors and their relative contribution to variations of flower and boll production.

Selected climatic factors	Flower production			Boll production		
	* R.C. (%)			R.C. (%)		
	First season	Second season	Combined data	First season	Second season	Combined data

Max Temp [°C] (X_1)	–	5.92	–	–	5.03	–
Evapor [mm d^{-1}] (X_4)	19.08	23.45	16.06	23.04	22.39	22.89
1800 h Temp [°C] (X_6)	–	–	5.83	–	–	2.52
Sunshine [h d^{-1}] (X_7)	9.43	7.77	8.31	11.65	7.88	5.47
Max RH [%] (X_8)	8.46	–	–	–	–	–
Min RH [%] (X_9)	–	4.37	7.38	–	4.26	4.64
** R^2 % for selected factors	36.97	41.47	37.58	34.69	39.56	35.52
R^2 % for factors studied	40.22	45.03	40.73	38.43	42.87	37.9
R^2 % for factors deleted	3.25	3.56	3.15	3.74	3.31	2.38

(Sawan et al., 2002).
* R.C. % = Relative contribution of each of the selected independent variables to variations of the dependent variable.
** R^2 % = Coefficient of determination in percentage form.

The highest contribution of evaporation to the variation in both flower and boll production can; however; be explained in the light of results found by Ward and Bunce [22] in sunflower (*Helianthus annuus*). They stated that decreases of humidity at both leaf surfaces reduced photosynthetic rate of the whole leaf for plants grown under a moderate temperature and medium light level. Kaur and Singh[23] 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 at flowering; slightly decreased by stress at boll formation; and not significantly affected by stress in the vegetative stage (6-7 weeks after sowing). Orgaz et al. [24] in field experiments at Cordoba; SW Spain; grew cotton cultivars Acala SJ-C1; GC-510; Coker-310 and Jean cultivar at evapotranspiration (ET) levels ranging from 40 to 100% of maximum ET (ET_{max}) which were generated with sprinkler line irrigation. The water production function of Jean cultivar was linear; seed yield was 5.30 t ha^{-1} 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.

The negative relationship between sunshine duration and cotton production may be due to the fact that the species of *Gossypium* used is known to be a short day plant [25]; so; an increase of sunshine duration above that needed for cotton plant growth will decrease flower and boll production. Oosterhuis [26] studied the reasons for low and variable cotton yields in Arkansas; with unusually high insect pressures and the development of the boll load during an exceptionally hot and dry August. Solutions to the problems are suggested i.e. selection of tolerant cultivars; effective and timely insect and weed control; adequate irrigation regime; use of proper crop monitoring techniques and application of plant growth regulators.

B- Effect of climatic factors during the development periods of flowering and boll formation on the production of cotton

Daily number of flowers and number of bolls per plant that survived to maturity (dependent variables) during the production stage of the two growing seasons are graphically illustrated in **Figures 5 and 6** [27]. Observations used in the statistical analysis were obtained during the flowering and boll stage (60 days for each season); which represent the entire production stage. The entire production stage was divided into four equivalent quarter's periods (15 days each) and used for correlation and regression analyses.

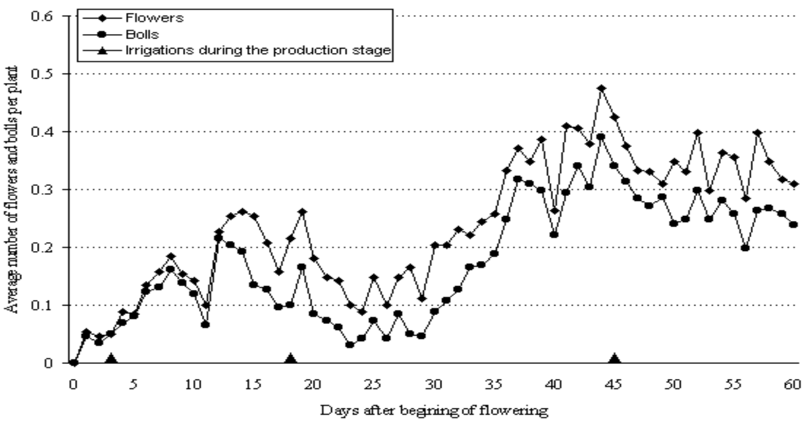

Figure 5. Daily number of flowers and bolls during the production stage (60 days) in the first season (I) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E), Egypt. The soil 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. 1999).

Independent variables; their range and mean values for the two seasons and during the periods of flower and boll production are listed in **Table 4.** Both flower number and boll production show the higher value in the third and fourth quarters of production stage; accounting for about 70% of total production during the first season and about 80% of the total in the second season[27].

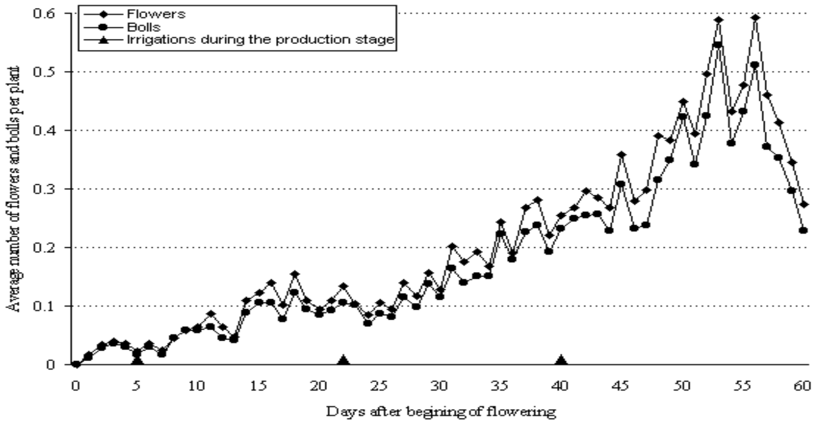

Figure 6. Daily number of flowers and bolls during the production stage (60 days) in the second season (II) for the Egyptian cotton cultivar Giza 75 (*Gossypium barbadense* L.) grown in uniform field trial at the experimental farm of the Agricultural Research Centre, Giza (30°N, 31°:28'E), Egypt. The 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. 1999).

Table 4. Range and mean value of the independent variables (climatic factors) during the four periods of flower and boll production stage.

Climatic factors	First period		Second period		Third period		Fourth period	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
First season								
MaxTemp °C, (X1)	31.0-37.3	33.7	33.0-37.3	34.7	32.4-37.2	34.5	32.0-38.4	33.8
Min Temp °C, (X2)	18.6-23.5	21.4	20.6-23.5	22.3	18.9-24.4	21.6	19.6-23.8	21.8
Max-Min °C, (X3)	9.4-14.8	12.3	9.8-15.6	12.4	9.7-18.3	12.9	9.5-14.6	12
Evapor. mm/d, (X4)	10.2-15.2	11.7	8.0-13.2	`10.1	7.6-11.2	9.1	7.7-11.1	9.2
0600 h Temp. °C, (X5)	14.2-19.9	16.8	15.8-21.5	18.9	13.9-21.1	17.4	15.4-20.8	18
1800 h Temp. °C, (X6)	22.0-25,2	23.8	22.2-27.0	24.2	19.6-25.6	24.1	21.8-26.0	23.9
Sunshine h/d, (X7)	11.4-12.9	12.4	10.4-12.4	11.5	10.5-12.4	11.6	9.9-12.2	11.4
Max Hum %, (X8)	62-88	80.7	84-94	88.4	85-96	89.9	76-96	87.4
Min Hum %, (X9)	21-37	28.2	22-43	31.4	17-42	29.9	24-45	34
Second Season								
MaxTemp °C, (X1)	31.4-38.8	35.5	31.4-35.5	33.4	32.6-37.9	34.4	30.6-34.6	32.8
Min Temp °C, (X2)	20.1-23.4	21.3	19.6-23.1	21.7	18.4-24.3	22.3	18.6-23.9	21.7
Max-Min °C, (X3)	9.4-17.6	14.2	10.1-15.0	11.7	9.6-17.0	12.1	8.5-12.6	11
Evapor. mm/d, (X4)	5.9-9.8	7.5	5.0-7.0	6	4.3-7.1	5.6	4.1-6.1	4.9
0600 h Temp. °C, (X5)	15.5-20.4	17.5	15.2-21.4	18.4	12.9-22.4	18.7	13.3-21.0	17.5
1800 h Temp. °C, (X6)	22.8-26.5	24.4	22.2-26.5	24.2	22.9-27.4	24.4	20.6-25.8	23.6
Sunshine h/d, (X7)	11.2-13.0	12.4	10.9-12.6	11.9	10.6-12.4	11.6	10.3-12.3	11.5
Max Hum %, (X8)	62-83	71.7	51-82	72.8	59-81	74.7	64-84	73.3
Min Hum %, (X9)	23-44	33.1	32-50	41.3	29-51	39.9	37-52	44.7
Windspeed m/s, (X_{10})	2.8-6.8	5.1	3.4-6.6	4.5	2.2-7.8	4.4	3.4-5.8	4.5
(Sawan et al., 1999)								

Linear correlation between the climatic factors and the studied characteristics; i.e. flower; boll production and boll retention ratio; were calculated based on quarters of the production stage for each season. Significant relationships (≤ 0.15) are shown in **Tables 5 and 6** [27]. Examining these tables; it is clear that the fourth quarter of production stage consistently exhibited the highest R^2 values regardless of the second quarter for boll retention ratio; however; less data pairs were used (n = 30 for combined data of the fourth quarter "n = 15 for each quarter of each season") to calculate the relations.

Table 5. Significant simple correlation values between the climatic factors and flower, boll production and boll retention ratio due to quarters of production stage.

Climatic factors	Flower				Boll				Ratio:Bolls/Flowers (100)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
First season (n by quarter = 15)												
MaxTemp °C, (X1)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s..
Min Temp °C, (X2)	0.516*	0.607*	n.s.	n.s.	0.561*	0.638**	n.s.	n.s.	n.s.	0.680**	n.s.	n.s.
Max-Min °C, (X3)	n.s.	n.s.	0.538*	n.s.	n.s.	n.s.	0.494*	n.s.	0.515*	n.s.	n.s.	n.s.
Evapor. mm/d, (X4)	0.512*	-0.598*	n.s.	0.424++	0.397+	-0.500*	-.0321+	n.s.	n.s.	-0.387+	-0.287+	n.s.
0600 h Temp. °C, (X5)	-0.352+	0.534*	-0.358+	0.301+	0.402+	0.516*	-0.441++	n.s.	n.s.	0.440++	n.s.	-.292+
1800 h Temp. °C, (X6)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Sunshine h/d, (X7)	n.s.	n.s.	0.346^{+}	n.s.	n.s.	n.s.	n.s.	0.430^{++}	n.s.	n.s.	n.s.	0.480*
Max Hum %, (X8)	-0.316^{+}	-0.260^{+}	0.461^{++}	0.283^{+}	n.s.	n.s.	0.410^{++}	n.s.	.389^{+}	n.s.	n.s.	-0.322^{+}
Min Hum %, (X9)	n.s.	0.309^{+}	-0.436^{++}	n.s.	n.s.	0.436^{++}	-0.316^{++}	n.s.	-0.473^{++}	0.527*	n.s.	n.s.
Second season (n by quarter = 15)												
MaxTemp °C, (X1)	n.s.	n.s.	n.s.	-0.730**	n.s.	n.s.	n.s.	-0.654**	n.s.	n.s.	0.407^{++}	n.s.
Min Temp °C, (X2)	n.s.	n.s.	n.s.	-0.451^{++}	n.s.	n.s.	n.s.	-0.343^{+}	n.s.	n.s.	n.s.	n.s.
Max-Min °C, (X3)	n.s.	n.s.	0.598*	n.s.	n.s.	n.s.	0.536*	n.s.	0.456^{++}	-0.416^{++}	n.s.	n.s.
Evapor. mm/d, (X4)	n.s.	n.s.	0.640**	n.s.	n.s.	n.s.	0.580*	n.s.	n.s.	-0.318^{+}	n.s.	n.s.
0600 h Temp. °C, (X5)	-0.397^{+}	-0.301^{+}	-0.407^{++}	-0.506*	-0.380^{+}	-0.323^{+}	-0.332^{+}	-0.426^{++}	n.s.	n.s.	0.283^{+}	n.s.
1800 h Temp. °C, (X6)	n.s.	-.0440^{++}	n.s.	-0.656**	n.s.	-0.410^{++}	n.s.	-0.582*	-.0626**	n.s.	n.s.	n.s.
Sunshine h/d, (X7)	0.362^{+}	n.s.	n.s.	n.s.	0.340^{+}	0.308^{+}	.354^{+}	n.s.	n.s.	0.409^{++}	n.s.	n.s.
Max Hum %, (X8)	-0.523*	0.424^{++}	-0.587*	n.s.	-0530*	0.431^{++}	-0.586*	n.s.	n.s.	n.s.	n.s.	n.s.
Min Hum %, (X9)	n.s.	n.s.	-0.585*	0.639**	n.s.	n.s.	-0.517*	0.652**	n.s.	n.s.	n.s.	0.420^{++}

n.s.: Means simple correlation coefficient is not significant at the 0.15 alpha level of significance.
**Significant at 1% probability level, * Significant at 5% probability level.
$^{++}$Significant at 10% probability level, + Significant at 15% probability level.
n: Number of data pairs used in calculation.
Wind speed did not show significant effect upon the studied production variables (Sawan et al., 1999).

Table 6. Significant simple correlation values between the climatic factors and flower, boll production, and boll retention ratio due to quarters periods of production stage for the combined data of the two seasons. (n =30).

Climatic factors	Flower				Boll				Ratio:Bolls/Flowers (100)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th
MaxTemp °C, (X1)	n.s.	n.s.	0.29^{+}	-0.48**	n.s.	n.s.	0.38^{++}	-0.47**	0.27^{+}	n.s.	n.s.	n.s.
Min Temp °C, (X2)	n.s.	n.s.	-0.35^{++}	n.s.	n.s.	n.s.	-0.28^{+}	n.s.	n.s.	n.s.	n.s.	n.s.
Max-Min °C, (X3)	-0.40*	-0.30^{+}	0.59**	-0.36^{++}	n.s.	-0.48**	0.52**	-0.38^{++}	-0.40*	-0.47**	n.s.	-0.28^{+}
Evapor. mm/d, (X4)	0.78**	n.s.	0.32^{++}	-0.67**	0.67**	-0.51**	n.s.	-0.74**	n.s.	-0.82**	-0.49**	-0.72**
0600 h Temp. °C, (X5)	n.s.	0.27^{+}	-0.43*	-0.31^{+}	n.s.	n.s.	-0.37^{++}	-0.37^{++}	n.s.	n.s.	n.s.	n.s.
1800 h Temp. °C, (X6)	n.s.	n.s.	n.s.	-0.42*	n.s.	n.s.	n.s.	-0.37^{++}	n.s.	n.s.	n.s.	n.s.
Sunshine h/d, (X7)	n.s.	n.s.	0.38^{++}	n.s.	n.s.	n.s.	0.32^{++}	n.s.	n.s.	0.30^{+}	n.s.	0.27^{+}
Max Hum %, (X8)	n.s.	n.s.	n.s.	-0.64**	n.s.	n.s.	n.s.	-0.71**	n.s.	-0.60**	-0.44*	-0.70**
Min Hum %, (X9)	n.s.	n.s.	-0.54**	0.69**	-0.32^{++}	0.42*	-0.37^{++}	0.72**	n.s.	0.72**	0.40*	0.56**
R^2	0.667	0.116	0.496	0.672	0.446	0.335	0.389	0.747	0.219	0.737	0.269	0.615
(Sawan et al., 1999)												

Results obtained from the four quarters of the production period for each season separately and for the combined data of the two seasons; indicated that relationships varied markedly from one season to another. This may be due to the differences between the climatic factors in the two seasons; as illustrated by its ranges and means shown in **Table 4** [27]. For example; maximum temperature and surface soil temperature at 1800 h did not show significant effects in the first season; while this trend differed in the second season.

Multiple linear regression equations obtained from data of the fourth quarter; for:

1. Flower production;

$Y = 160.0 + 11.28X_1 - 4.45X_3 - 2.93X_4 - 5.05X_5 - 11.3X_6 - 0.962X_8 + 2.36X9$

And $R^2 = 0.672^{**}$

2. Boll production;

$Y = 125.4 + 13.74X_1 - 6.76X_3 - 4.34X_4 - 6.59X_5 - 10.3X_6 - 1.25X_8 + 2.16X9$

With an $R^2 = 0.747^{**}$

3. Boll retention ratio;

$Y = 81.93 - 0.272X_3 - 2.98X_4 + 3.80X_7 - 0.210X_8 - 0.153X_9$

And its $R^2 = 0.615^{**}$

The equation obtained from data of the second quarter of production stage for boll retention ratio;

$Y = 92.81 - 0.107X_3 - 0.453X_4 + o.298X_7 - 0.194X_8 + 0.239X_9$

And $R^2 = 0.737^{**}$

R^2 values for these equations ranged from 0.615 to 0.747. It could be concluded that these equations may predict flower and boll production and boll retention ratio from the fourth quarter period within about 62 to 75% of its actual means. Therefore; these equations seem to have practical value. Comparing **Tables 6 and 7**; it can be seen that differences in R^2 between the fourth quarter and the entire production period of the two seasons for each of flower; boll production; and boll retention ratio were large (0.266; 0.325; and 0.279 respectively). These differences are sufficiently large to make a wide gap under a typical field sampling situation. This could be due to the high percentage of flower and boll production for the fourth quarter.

Table 7. Significant simple correlation values between the climatic factors and flower, boll ratio for combined data of the two seasons (n = 120). production and boll retention.

Climatic factors	Flower	Boll	Ratio:Bolls/Flowers (100)
MaxTemp °C, (X1)	-0.152++	n.s.	n.s.
Min Temp °C, (X2)	n.s.	n.s.	n.s.
Max-Min °C, (X3)	-0.259**	-0.254**	n.s.
Evapor. mm/d, (X4)	-0.327**	-0.429**	-0.562**
0600 h Temp. °C, (X5)	n.s.	n.s.	n.s.
1800 h Temp. °C, (X6)	-0.204*	-0.190++	n.s.
Sunshine h/d, (X7)	-0.227*	-0.180++	n.s.
Max Hum %, (X8)	n.s.	n.s	-0.344**.
Min Hum %, (X9)	0.303**	0.364**	0.335**
R^2	0.406**	0.422**	0.336*
(Sawan et al., 1999)			

Equations obtained from data of the fourth quarter explained more variations of flower; boll production and boll retention ratio. Evaporation; humidity and temperature are the principal climatic factors that govern cotton flower and boll production during the fourth quarter; since they were most strongly correlated with the dependent variables studied **(Table 6).**

Evaporation; that seems to be the most important climatic factor; had negative significant relationship which means that high evaporation ratio reduces significantly flower and boll production. Maximum temperature; temperature-differentiates and maximum humidity also showed negative significant link with fruiting production; which indicates that these climatic variables have determinable effect upon Egyptian cotton fruiting production. Minimum humidity was positively high correlated in most quarter periods for flower; boll production and boll retention ratio. This means that an increase of this factor will increase both flower and boll production. Maximum temperature is sometime positively and sometime negatively linked to boll production **(Table 6).** These erratic correlations may be due to the variations in the values of this factor between the quarters of the production stages; as shown from its range and mean values **(Table 4)** [27].

Burke et al. [28] pointed out that the usefulness of the 27.5°C midpoint temperature of the TKW of cotton as a baseline temperature for a thermal stress index (TSI) was investigated in field trials on cotton cv. Paymaster 104. This biochemical baseline and measurements of foliage temperature were used to compare the TSI response with the cotton field performance. Foliage temperature was measured with hand-held 4°C field of view IR thermometer while plant biomass was measured by destructive harvesting. The biochemical based TSI and the physically based crop water stress index were highly correlated (r^2 = 0.92) for cotton across a range of environmental conditions. Reddy et al.[29] in controlled environmental chambers pima cotton cv. S-6 produced less total biomass at 35.5°C than at 26.9°C and no bolls were produced at the higher temperature 40°C. This confirms the results of this study as maximum temperature showed negative significant relationship with production variables in the fourth quarter period of the production stage. Zhen (1995) found that the most important factors decreasing cotton yields in Huangchuan County; Henan; were low temperatures in spring; high temperatures and pressure during summer and the sudden fall in temperature at the beginning of autumn. Measures to increase yields included the use of the more suitable high-oil cotton cultivars; which mature early; and choosing sowing dates and spacing so that the best use was made of the light and temperature resources available.

It may appear that the grower would have no control over boll shedding induced by high temperature; but this is not necessarily the case. If he can irrigate; he can exert some control over temperature since transpiring plants have the ability to cool themselves by evaporation. The leaf and canopy temperatures of drought-stressed plants can exceed those of plants with adequate quantity of water by several degrees when air humidity is low (Ehrler; 1973). The grower can partially overcome the adverse effects of high temperature on net photosynthesis by spacing plants to adequately expose the leaves. Irrigation may also increase photosynthesis by preventing stomata closure during the day. Adequate fertilization is necessary for maximum rates of photosynthesis. Finally; cultivars appear to differ in their heat tolerance [30]. Therefore; the grower can minimize boll abscission where high temperatures occur by selecting a heat-tolerant cultivar; planting date management; applying an adequate fertilizer; planting or thinning for optimal plant spacing; and irrigating as needed to prevent drought stress [31-36].

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 the fourth quarter period of the production stage is the most appropriate and usable production time to collect data for determining efficient prediction equations for cotton flower and boll production in Egypt; and making valuable recommendations. 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 [37]. 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. 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. 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.

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