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Response of flower and boll development to climatic factors before and after anthesis in Egyptian cotton

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ABSTRACT: Understanding the impact that climatic factors have on cotton production may help physiologists to determine possible control mechanisms which influence the flowering of cotton plants. This study was conducted to investigate the nature of the effects of climatic factors prevailing prior and subsequent to either flowering or boll setting on flower and boll production and retention in Egyptian cotton *Gossypium barbadense* L. Two uniform field trials using the cotton cultivated variety Giza 75 were carried out at the Agricultural Research Center, Giza, Egypt. Randomly chosen plants were used to record daily numbers of flowers and bolls during the production stage (68 d in Season I and 62 d in Season II). The daily records of the climatic factors (air temperature, diurnal temperature range, evaporation, soil surface temperature, sunshine duration, and humidity) were recorded during the entire period of production and also for the 15 d periods before and after anthesis. The effects of climatic factors on flower and boll production were quantified in non-limiting management techniques. Relationships in the form of simple and multiple correlations were computed between climatic factors and flower and boll production and retention. The data indicated that 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 the same correlation with minimum humidity was positive. Thus, it appeared that low evaporation rate, reduced sunshine duration and high humidity would enhance flower and boll formation. Accordingly, the deleterious effects of climatic factors on cotton production could be minimized through applying appropriate production practices, which would control and adjust the impact of these factors and thus potentially lead to an important improvement in cotton yield in Egypt.

KEY WORDS: Boll retention · Evaporation · Flower and boll production · Humidity · Sunshine duration · Temperature

1. INTRODUCTION

Different species and cultivars of plants respond differently to climatic factors depending on the growth stage. Climatic influences are modified by other environmental factors such as water or nitrogen availability. The dynamic nature of climatic and environmental factors and their impact on plant response render it difficult to determine 'cause–effect relationships'. 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.

Temperature is an extremely important climatic factor determining cotton growth and development. However, extremes in temperature can greatly impair growth and boll development. Cool nighttime temper-

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atures (<20°C) slow boll development (Gipson & Joham 1968), while high nighttime temperatures (>29°C) render pollen non-viable (Powell 1969). Fisher (1975) found that high temperatures can cause male sterility in cotton (Upland cotton) flowers, and increase boll shedding late in the fruiting season. El-Zik (1980) stated that many factors, such as length of the growing season, climate (including solar radiation, temperature, light, wind, rainfall, and dew), cultivar, nutrient availability, soil moisture, pests and cultural practices, affect cotton growth. 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 humidity (Guinn 1982). Reddy et al. (1990) found that cotton cultivar (cv.) ST825 plants grown at optimum temperature (30/20°C day/nighttime temperatures) partitioned nearly 43% of their total biomass to reproductive structures (bolls and squares) compared with 13 to 15% for plants grown at a lower temperature. At higher temperatures, biomass partitioned to reproductive parts was negligible. Hodges et al. (1993) found that the optimum temperature for cotton stem and leaf growth, seedling development, and fruiting was almost 30°C. Fruit retention decreased rapidly as the time of exposure to 40°C increased. In growth chamber experiments, Reddy et al. (1995) 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 a temperature of 40°C. Furthermore, Reddy et al. (1996) observed that when cotton cv. DPL-51 was grown in controlled environments under natural solar radiation, flower and fruit retentions were very low at an ambient temperature ranging from 31 to 40°C. They concluded that cotton could be severely damaged by temperatures above those found during mid-summer in the cotton belt in the United States of America.

In Egypt, field studies relating cotton flower and boll production to climatic factors are few. Production of field-grown cotton plants is 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. Because the climatic factors are largely uncontrolled, the variables that influence flower and boll production must be quantitatively evaluated to adequately explain the effects of any climatic variable on cotton flower and boll production. Thus, it is important to determine the significant climatic factors that affect cotton production and their magnitudes.

The work reported here raises a question regarding the nature of the effects of specific climatic factors during both pre- and post-anthesis periods on boll production and retention. Hence, the objective of this investigation was to study and collect information about the nature of the relationship between various climatic factors and cotton boll development and the 15 d period both prior to and after initiation of individual bolls of field-grown cotton plants in Egypt. This could pave the way for formulating advanced predictions regarding the effect of certain climatic conditions on production of Egyptian cotton. Knowledge of the climatic influences will allow growers to adopt various cultural practices that can potentially lead to improvements in cotton yield. It would be useful to minimize the deleterious effects of the climatic factors through utilizing proper cultural practices which would limit and control their negative effects, and this will lead in turn to an improvement in cotton yield. As a matter of fact an understanding of the relationships between climatic factors, flowering and boll retention patterns of the cotton plants during these periods might allow a direct external intervention that can help cotton growth and production.

2. DATA AND METHODS

Two uniform field trials were conducted at the experimental farm of the Agricultural Research Center, Ministry of Agriculture, Giza, Egypt (30° N, 31° 28′ E), 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).

Total water consumption during each of the 2 growing seasons supplied by surface irrigation was about 6000 m^3 ha^{-1}. The criteria used for watering the crop depended on soil water status, where irrigation was applied when soil water content reached about 35% of field capacity. 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 its 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 wk after planting, resulting in a plant density of about 166000 plants ha^{-1}. Phosphorus fertilizer was applied at a rate of 54 kg P_2O_5 ha^{-1} as calcium superphosphate during land

Table 1. Example of a file containing daily recorded data for variables tested from Season I of cotton growth

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

preparation. Potassium fertilizer was applied at a rate of 57 kg K_2O ha^{-1} as potassium sulphate before the first irrigation. Nitrogen fertilizer was applied at a rate of 144 kg N ha^{-1} as ammonium nitrate with lime at 2 equal doses: the first applied after thinning just before the second irrigation and the other applied before the third irrigation. Rates of phosphorus, potassium, and nitrogen fertilizer were the same in both years.

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 2 hills in each ridge) from 9 and 11 inner ridges of the plot in Seasons I and II, respectively. Flowers of 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), which would give sound bolls at the end of the picking season (20 October). Each flower was tagged according to date of appearance on the selected plants. 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 are not expected to form sound bolls, and therefore were not taken into account.

Observation of flowering started when the number of flowers on a given day was ≥5 flowers per 100 plants and this continued for at least 5 consecutive days. Accordingly, observations were taken throughout the flowering season except for the first 6 and 8 d at the onset of flowering stage and 2 d just before its termination in Seasons I and II, respectively. Thus, flower and boll production stage extended for 68 and 62 d during Seasons I and II, respectively, i.e. from 23 June to 29 August and from 29 June to 29 August.

For statistical analysis, the following data of the dependent variables were determined: (1) daily number of tagged flowers separately counted each day on all selected uniform plants; (2) number of retained bolls obtained from the total of each daily tagged flower on all selected plants at harvest; and (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 in all selected plants] × 100).

Daily records of the climatic factors (independent variables) were taken during the production stage in any season including 2 additional periods of 15 d before and after the production stage.

In each season, the data of the dependent and independent variables (68 and 62 d) 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 of 1 d (either before or after production stage) in a matter similar to a sliding role. Table 1 shows an example (for Season I).

Thus, the climate data were organized into records according to the complete production stage (68 d in Season I and 62 d in Season II) and 15 d, 14 d, 13 d, …. 1 d 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.

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 d^{-1}, X_4); soil surface temperature (grass temperature or green cover temperature) at 06:00 (°C, X_5) and 18:00 h (X_6); sunshine duration (h d^{-1}, X_7); maximum humidity (%, X_8); minimum humidity (%, X_9) and wind speed (m s^{-1}, X_{10}) (in Season II only). The maximum and minimum air temperatures were measured using mercury and alcohol thermometers which were freely exposed to the environment in louvered screens, with their bulbs at a height of 160 cm above the ground. Evaporation measurements were taken once daily at 06:00 h, giving the evaporation readings for the previous 24 h.

The evaporation readings were measured by a Piche tube which was freely exposed in sloping double-roofed louvred screens. The evaporation disc has an effective area of 10.1 cm^2, is white in colour, and was placed at a height of 150 cm above ground. Soil surface temperatures were taken regularly in the dry and grass-covered fields at 06:00 and 18:00 h. Surface grass thermometers were used. The actual duration of bright sunshine in a day is the period calculated between sunrise and sunset; this was measured by Campbell-Stokes sunshine recorders which were suitably exposed. The relative humidity (%) was derived from the dry- and wet-bulb thermometer readings using Jellink's Psychrometer Tables. No corrections for wind speed or atmospheric pressure were applied. Routine observations of the surface wind speed were taken at the principal synoptic hours 06:00, 12:00 and 18:00 h using a cup-anemometer whose head was freely exposed and erected at 2 m above ground. The daily mean surface wind speed was the arithmetic mean of the surface wind speed observations at these 3 principal synoptic hours. All the climatic factors were measured according to the methodological directions adapted by the World Meteorology Organization (WMO). 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 2 growing seasons.

Mean, standard deviation, maximum and minimum values of the climatic parameters for the original file (flower and boll stage), and the 15 d periods preceding flowering or subsequent to boll setting in both seasons are shown in Table 2.

Simple correlation coefficients were computed between the original dependent variables (boll setting and boll retention) and the independent variables for each of the original file and the 15 new files just before or after flowering in each season. The significance of the simple correlation at a probability level not exceeding 5% was tested to determine the factors affecting the dependent variables. The relationship between the most effective and consistent climatic factors affecting flower and boll production and retention was computed using the stepwise regression analysis method. Linear regression equations comprising selected predictive variables were computed and coefficients of determination were calculated to measure the efficiency of the regression models in explaining the variation in the data. The statistical analysis was carried out in accordance with Draper & Smith (1966), by means of the computer program SAS package (1985) using the procedures outlined in the general linear model (GLM) (SAS Institute 1985).

3. RESULTS AND DISCUSSION

Daily number of flowers and number of bolls per plant which survived to maturity (dependent variables) during the production stage of the 2 growing seasons (68 and 62 d in Seasons I and II, respectively) are illustrated in Figs. 1 & 2. The flowering- and bolling-curves reached their peaks during the middle 2 wk of August, and then descended steadily till the end of the season. Specific differences in the shape of these curves in the 2 seasons may be due to the environmental effects on growth, for which climatic factors (Table 2) play an important role (Miller et al. 1996).

3.1. Correlation estimates

Results of the correlation between climatic factors and both flower and boll production during the 15 d periods before flowering day (Tables 3 & 4) revealed the following for Season I: Daily evaporation and sunshine

Table 2. Mean, standard deviation, maximum and minimum values of the climatic factors (X_1 to X_{10}) during the cotton flower and boll stage (initial time) and the 15 d prior to flowering or subsequent to boll setting for Seasons I and II. Flower and boll stage lasted 68 d (23 June–29 August) for Season I and 62 d (29 June–29 August) for Season II. Max.–Min.: diurnal temperature range; ND: not determined; Evap.: evaporation; SS temp.: soil surface temperature

	Air temp. (°C)			Evap.	SS temp. (°C)		Sunshine	Humidity (%)		Wind speed
	Max. (X_1)	Min. (X_2)	Max.–Min. (X_3)	(mm d^{-1}) (X_4)	06:00 (X_5)	18:00 (X_6)	duration (h d^{-1}) (X_7)	Max. (X_8)	Min. (X_9)	(m s^{-1}) (X_{10})
Season I										
Mean (SD)	34.1 (1.2)	21.5 (1.0)	12.6 (1.1)	10.6 (1.6)	17.5 (1.1)	24.2 (1.9)	11.7 (0.8)	85.6 (3.3)	30.2 (5.2)	ND
Max.	44.0	24.5	20.9	16.4	21.5	32.3	12.9	96.0	45.0	ND
Min.	31.0	18.6	9.4	7.6	13.9	19.6	9.9	62.0	11.0	ND
Season II										
Mean (SD)	33.8 (1.2)	21.4 (0.9)	12.4 (1.3)	6.0 (0.7)	17.6 (1.2)	23.7 (1.1)	11.7 (0,4)	72.9 (3.8)	39.1 (5.0)	4.6 (0.9)
Max.	38.8	24.3	17.6	9.8	22.4	27.4	13.0	84.0	52.0	7.8
Min.	30.6	18.4	8.5	4.1	13.3	20.6	10.3	51.0	23.0	2.2

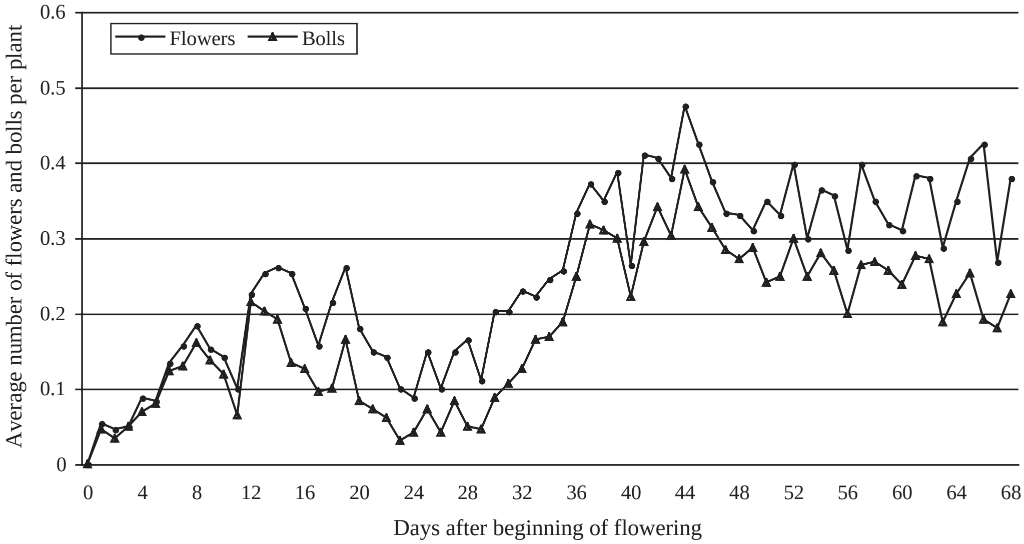

Fig. 1. *Gossypium barbadense.* Daily number of flowers and bolls during the production stage (68 d) in Season I for the Egyptian cotton cultivar Giza 75, grown in a uniform field trial (see 'Data and methods' for details). Sampling size was 261 plants

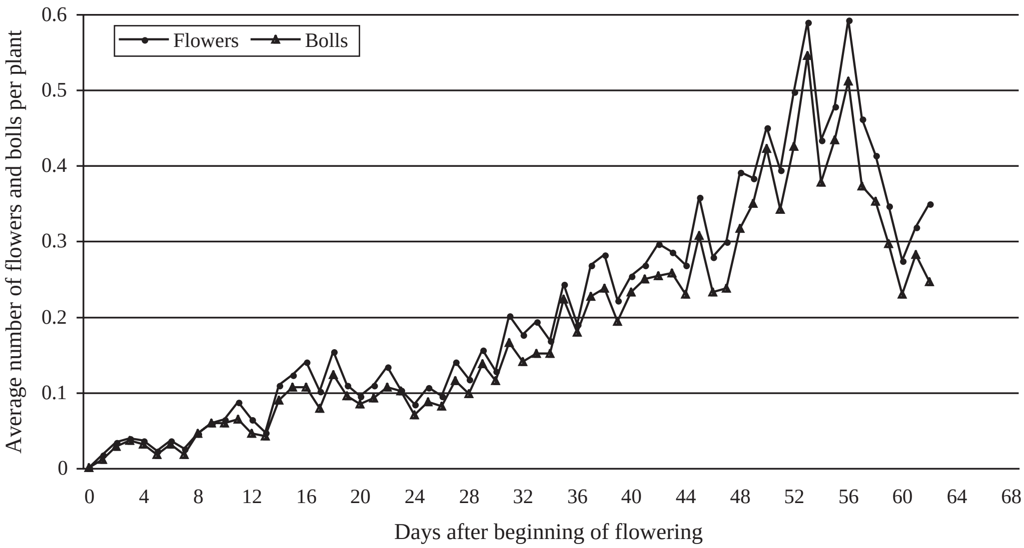

Fig. 2. *Gossypium barbadense.* Daily number of flowers and bolls during the production stage (62 d) in Season II for the Egyptian cotton cultivar Giza 75, grown in a uniform field trial (see 'Data and methods' for details). Sampling size was 358 plants

duration showed consistent negative and statistically significant correlations with both flower and boll production for each of the 15 moving window periods before anthesis. 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 3). Maximum daily temperature showed low but significant negative correlation with flower production during the 2 to 5, 8, and 10 d 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 06:00 h showed a significant positive correlation with boll production during the period extending from the 11 to 15 d period before anthesis, while its effect on flowering was confined only to the 12 and 15 d periods prior to anthesis. Daily soil surface temperature at 18:00 h showed a significant negative correlation with flower production during the 2 to 10 d periods before anthesis.

Table 3. Simple correlation coefficients (r) between climatic factors and number of flower and harvested bolls in initial time (0) and each of the 15 d periods before flowering in Season I. *: significant at 5% level; **: significant at 1% level. Max.–Min.: diurnal temperature range; Evap.: evaporation; SS temp.: soil surface temperature

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)	SS temp. (°C) 06:00 h (X_5)	SS temp. (°C) 18:00 h (X_6)	Sunshine duration (h d^{-1}) (X_7)	Humidity (%) Max. (X_8)	Humidity (%) Min. (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*

For Season II, daily evaporation, the diurnal temperature range, and sunshine duration were negatively and significantly correlated with both flower and boll production in all the 15 d periods, while maximum daily temperature was negatively and significantly related to flower and boll formation during the 2 to 5 d periods before anthesis (Table 4).

Minimum daily temperature showed positive and statistically significant correlations with both production variables only during the 9 to 15 d 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 06:00 h was positively and significantly correlated with both flower and boll production for the 12, 14, and 15 d periods prior to anthesis only. Daily soil surface temperature at 18:00 h showed negative and significant correlations with both production variables only during the 1 and 2 d periods before flowering. Daily maximum humidity showed insignificant correlation with both flower and boll production except for the 15 d period.

Generally, the results in the 2 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 d periods before anthesis in both seasons.

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,

Table 4. Simple correlation coefficients (r) between climatic factors (wind speed not reported on as it did not show significant effects) and number of flower and harvested bolls in initial time (0) and each of the 15 d periods before flowering in Season II. *: significant at 5% level; **: significnat at 1% level. Max.–Min.: diurnal tempeature range; Evap.: evaporation; SS temp.: soil surface temperature

Climate period		Air temp. (°C)			Evap.	SS temp. (°C)		Sunshine	Humidity (%)	
		Max. (X_1)	Min. (X_2)	Max.–Min. (X_3)	(mm d^{-1}) (X_4)	06:00 h (X_5)	18:00 h (X_6)	duration (h d^{-1}) (X_7)	Max. (X_8)	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**

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

The correlation between climatic factors and both boll production and boll retention over sets of 15 d periods after flowering (boll setting) day (Tables 5 & 6) revealed the following in Season I. Daily evaporation showed significant negative correlation with number of bolls for all the 15 d periods after flowering (Table 5). Meanwhile its relationship with retention ratio was positive and significant in the 9 to 15 d periods after flowering. Daily sunshine duration was positively and significantly correlated with boll retention ratio during the 5 to 13 d periods after flowering. Daily maximum humidity had a significant positive correlation with the number of bolls during the first 8 d periods after flowering, while daily minimum humidity had the same correlation for only the 11 and 12 d periods after flowering. Daily maximum and minimum temperatures and the diurnal temperature range, as well as soil surface temperature at 18:00 h did not show significant relationships with either number of bolls or retention ratio. Daily soil surface temperature at 06:00 h had a significant negative correlation with boll retention ratio during the 3 to 7 d periods after anthesis.

In Season II, daily evaporation, soil surface temperature at 18:00 h, and sunshine duration had a significant negative correlation with number of bolls in all the 15 d periods after anthesis (Table 6). Daily maximum and minimum temperatures, the diurnal temperature range, and soil surface temperature at 06:00 h had a negative correlation with boll production. Their significant effects were observed during the 1 and 10 to 15 d periods for maximum temperature, and the 1 to 5 and 9 to 12 d periods for the diurnal temperature range. Meanwhile, the daily minimum temperature and soil surface temperature at 06:00 h had a significant negative correlation only during the 13 to 15 d periods. Daily minimum humidity had a significant positive correlation with number of bolls during the first 5 d periods, and the 9 to 15 d periods after anthesis. Daily maximum humidity showed no significant relation to number of bolls produced, and further no significant relation was observed between any of the studied climatic factors and boll retention ratio.

The results for Seasons I and II 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 Season I, i.e. did not show any significant effects on the number of bolls per plant.

Table 5. Simple correlation coefficient (r) values between climatic factors and number of harvested bolls and retention ratio ([number of retained bolls obtained from the total number of daily tagged flowers in all selected plants at harvest/daily number of tagged flowers in all selected plants] × 100) in initial time (0) and each of the 15 d periods after flowering in Season I. Max.–Min.: diurnal temperature range. *: significant at 5% level; **: significant at 1% level. Evap.: evaporation; SS temp.: soil surface temperature

Climate period		Air temp. (°C) Max. (X_1)	Min. (X_2)	Max.–Min. (X_3)	Evap. (mm d^{-1}) (X_4)	SS temp. (°C) 06:00 h (X_5)	18:00 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

However, these effects were found to be significant in Season II. 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 clear variation in evaporation values in the 2 seasons studied, where their means were 10.2 and 5.9 mm d^{-1} in Seasons I and II, respectively.

At this juncture, an important question must be asked: is there a way for forecasting when evaporation values would mask the effect of the previous climatic factors? The answer might possibly be achieved by 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 mean maximum humidity and mean evaporation in Season I was 85.8/10.2 = 8.37, while in Season II this ratio was 12.4. In contrast, the ratio between mean minimum humidity and mean evaporation in Season I was 30.8/10.2 = 3.02, while in Season II this ratio was 6.75 (Table 2). From these ratios it seems that minimum humidity, which is closely related to evaporation, is more sensitive (for forecasting) 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.

Table 6. Simple correlation coefficient (r) values between climatic factors (wind speed not reported on as it did not show significant effects) and number of harvested bolls and retention ratio ([number of retained bolls obtained from the total number of daily tagged flowers in all selected plants at harvest/daily number of tagged flowers in all selected plants] × 100) in initial time (0) and each of the 15 d periods after flowering in the second season (II). Max.–Min.: diurnal temperature range. *: significant at 5% level; **: significant at 1% level; Evap.: evaporation; SS temp.: soil surface temperature

Climate period		Air temp. (°C) Max. (X_1)	Min. (X_2)	Max.–Min. (X_3)	Evap. (mm d^{-1}) (X_4)	SS temp. (°C) 06:00 h (X_5)	18:00 h (X_6)	Sunshine duration (h d^{-1}) (X_7)	Humidity (%) Max. (X_8)	Min. (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*

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.

Evaporation appeared to be the most important climatic factor (in each of the 15 d periods prior to and after initiation of individual bolls) affecting number of flowers or harvested bolls in Egyptian cotton. High daily evaporation rates could result in water stress that would slow growth and increase the shedding rate of flowers and bolls. This finding can, however, be explained in the light of results found by Ward & Bunce (1986) in the sunflower *Helianthus annuus*. They stated that decreases in humidity at both leaf surfaces reduced the photosynthetic rate of the whole leaf for plants grown under a moderate temperature and medium light level. Kaur & Singh (1992) found that cotton flower number was decreased by water stress, particularly when this stress was present at the flowering period. Seed cotton yield was halved by water stress at flowering, slightly decreased by stress at boll formation and not significantly affected by stress in the vegetative stage (6 to 7 wk after sowing). Orgaz et al. (1992), in field experiments at Cordoba, south-west Spain, grew cotton cv. Acala SJ-C1, GC-510, Coker-310 and Jean at evapotranspiration (ET) levels generated with sprinkler line irrigation from 40 to 100 % of maximum ET (ET_{max}). The water production function of Jean cultivar was linear; seed yield was 5.30 t ha^{-1} at ET_{max} (820 mm). In contrast, the production function of the 3 other cultivars approached ET_{max} (830 mm) because a fraction of the set bolls did not open by harvest at high ET levels. They 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 second most important climatic factor in our study was humidity. The effect of maximum humidity varied markedly from Season I to Season II, it was significantly correlated with the dependent variables in Season I, while the inverse pattern was true in Season II. This diverse effect may be due to the differences in the values of this factor in the 2 seasons; it was on average 87 % in Season I, and only 73 % in Season II (Table 2). In addition, when the average value of minimum humidity exceeded half the average value of maximum humidity, the minimum humidity can substitute the maximum humidity which affects the number of flowers or harvested bolls. In Season I (Table 2) the average value of minimum humidity was less than half the value of maximum humidity (30.2/85.6 = 0.35), while in Season II it was higher than half of maximum humidity (39.1/72.9 = 0.54).

The third most important climatic factor in this study was sunshine duration, which showed a significant negative relationship with boll production. This negative relationship between sunshine duration and cotton production might be due to the fact that the species of the genus *Gossypium* are known to be short-day plants (Hearn & Constable 1984). Thus, an increase in 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 h and high day-time temperatures, either individually or in combination, delayed flowering of the Upland cotton cv. J 34. Although average sunshine duration in the present study was only 11.7 h, it could reach 13 h, which in combination with high maximum temperatures (up to 44°C) may have an adverse effect on flower and boll formation.

The r values of (Tables 3 to 6) indicated that the relationship between the dependent and independent variables preceding flowering (production stage) generally exceeded 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.

3.2. Regression models

An attempt was made to investigate the effect of climatic factors on cotton production using prediction equations including the important climatic factors responsible for the majority of total variability in cotton flower and boll production. Regression models were established using the stepwise multiple regression technique to express the relationship between the number of flowers and bolls/plant and boll retention ratio (Y), with the climatic factors, for each of the 5, 10, and 15 d periods either prior to or after initiation of individual bolls (Tables 7 & 8).

Concerning the effect of prior days, the results indicated that evaporation, sunshine duration, and the diurnal temperature range were the most effective and consistent climatic factors affecting cotton flower and boll production (Table 7). The 4th effective climatic factor in this respect was minimum humidity. In contrast, for the periods after flowering the results obtained from the equations in Table 8 indicated that evaporation was the most effective and consistent climatic factor affecting the number of harvested bolls.

Regression models showed that each independent variable under study was an efficient and important factor. Meanwhile, they explained a majority proportion of the variation in flower and boll production, as indicated by their R^2 value, which ranged between

Table 7. Models obtained for the number of flowers and bolls per cotton plant as functions of the climatic data derived from the 5 (Y_1), 10 (Y_2), and 15 d (Y_3) periods prior to flower opening in Seasons I and II. X values as in Table 2. All entries significant at 1% level

Model	R^2
Season I	
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
Season II	
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

0.14 and 0.62, where most R^2 values prior to flower opening were about 0.50 and after flowering all but one were less than 0.50. These results agree with Miller et al.'s (1996) study which investigated the relation of yield to rainfall and temperature using regressions also. They suggested that the other 0.50 of variation related to management practices, which could be relevant in this present study. In addition, the regression models indicated that the relationships between the number of flowers and bolls per plant and the studied climatic factors for the 15 d 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 d periods before and after flowering were higher than most of those obtained for each of the 5 and 10 d periods before or after flowering. This clarifies that the effects of the climatic factors during the 15 d periods before or after flowering are very important for Egyptian cotton boll production and retention. Thus, an accurate climatic forecast for these 15 d 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, are evaporation, sunshine duration and minimum humidity, with evaporation (water stress) being by far the most important factor. Various activities have been suggested to partially overcome water stress. Zhao & Oosterhuis (1997) found that when under water stress, in a growth chamber, cotton plants treated with the plant growth regulator PGR-IV developed higher root and floral bud dry weights than the untreated water-stressed plants. In contrast, Moseley et al. (1994) reported that methanol increased water use efficiency, growth and development of C_3 plants. Under mild water stress, Meek et al. (1999) found that the application of 3 or 6 kg glycin betaine (PGR) ha^{-1} increased yields.

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 reproduction growth. This is contradictory to the finding of Mergeai & Demol (1991) and Holaday et al. (1997). A possible reason for this 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. 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. Sunshine duration and minimum humidity appeared to have secondary effects on cotton reproduction growth, yet they are in fact important players. The importance of sunshine duration has been alluded to by Moseley et al. (1994) and Oosterhuis (1997). In addition, Mergeai & Demol (1991) found that cotton yield was assisted by intermediate relative humidity.

Other workers, studying the effect of weather factors on cotton boll production and retention and, in turn, yield, found different relationships. They found that temperature was often the major factor affecting cotton growth. In this respect, Burke et al. (1988) defined the thermal kinetic window (TKW) as the optimum temperature range for biochemical and metabolic activities of plants (a temperature range that permits normal enzyme functions in plants). The TKW for cotton

Table 8. Models obtained for the number of bolls per plant as functions of the climatic data derived from the 5 (Y_1), 10 (Y_2), and 15 d (Y_3) periods after flower opening in Seasons I and II. X values as in Table 2. All entries significant at 1% level

Model	R^2
Season I	
$Y_1 = 16.38 - 0.41X_4$	0.14
$Y_2 = 16.43 - 0.41X_4$	0.14
$Y_3 = 27.83 - 0.60X_4 - 0.88X_9$	0.15
Season II	
$Y_1 = 23.96 - 0.47X_4 - 0.77X_8$	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

growth is 23.5 to 32°C, with an optimum temperature of 28°C. Plant temperature above or below the TKW resulted in stress that limited growth and yield. Mergeai & Demol (1991) in phytotron trials in Belgium found that cotton yield was favoured by intermediate relative humidity (60%) and temperatures of 24 to 28°C. Under long photoperiods (16 h), low nighttime temperature (12°C) increased negative effects on both growth and cotton yields, but under short photoperiods (12 h) yields were better with a higher nighttime temperature (16°C). Warner & Burke (1993) indicated that the cool nighttime inhibition of cotton growth is correlated with biochemical limitation on starch mobilization in source leaves, which results in a secondary inhibition of photosynthesis, even under optimal temperatures during the day. Holaday et al. (1997) in growth chamber experiments with cotton cv. Coker 312 showed that cool nighttimes (15 or 19°C) reduced photosynthetic efficiency compared with warm nighttimes (28°C). This is ascribed to reducing stomatal conductance, resulting in lower sucrose levels during the day and reduced ability to export sucrose from the leaf to storage places. Oosterhuis (1997) reported that the reason for low and variable cotton yields in Arkansas, were the unusually high insect pressures and the development of the boll load during an exceptionally hot, dry August. Suggested solutions to these problems were 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. Reddy et al. (1998) found that when Upland cotton *Gossypium hirsutum* cv. DPL-51 was grown in naturally lit plant growth chambers at 30/22°C day/night temperatures from sowing until floral bud production, and at 20/12, 25/17, 30/22, 35/27 and 40/32°C for 42 d after floral bud production, fruit retention was severely curtailed at the 2 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 so in a future warmer world.

Miller et al. (1996) reported that regression analysis of the relationship of yield with rainfall and temperature (data gathered during the period 1968 to 1992) indicated that in most cases about 50% of the yield variation for dry land cotton could be explained by a combination of weather factors. The other 50% of yield variation was ascribed to management of cultural practices. In the present study, maximum temperatures were above the optimum for cotton growth found by Mergeai & Demol (1991), while, the minimum temperature during this period was 22°C, which, combined with short days (11.8 h), probably favoured growth. Therefore, temperature conditions during the reproductive growth stage of cotton in Egypt do not appear to limit growth.

4. CONCLUSIONS

From the results obtained in the present study, it could be generally concluded that during the 15 d periods both prior to and after initiation of individual bolls, evaporation, minimum 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 evaporation and sunshine duration with flower and boll formation along with the positive correlation between minimum 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 reproductive 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 this 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. It is probable that because temperature and evaporation are closely related to each other, 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 as for the Egyptian cotton. It must be kept in mind that although the reliable prediction of the effects of the aforementioned climatic factors could lead to higher yields of cotton, only 50% of the variation in yield could be statistically explained by these factors and hence the management practices in use at present should also be considered. The least important climatic factors were minimum air temperature and soil surface temperature at 06:00 h. In conclusion, the early prediction of possible adverse effects of climatic factors could pave the way for adopting adequate precautions regarding the effect of certain climatic factors on production of Egyptian cotton. This would be useful to minimize the deleterious effects of these factors, through the application of adequate management practices, i.e. adequate irrigation regime (Orgas et al. 1992, Oosterhuis 1997), as well as utilization of specific plant growth regulators (Mosely et al. 1994, Zhao & Oosterhuis 1997, Meek et al. 1999) which would limit and control the negative effects of some climatic factors, and this will lead to an improvement in cotton yield production in Egypt.

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