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REGULAR ARTICLE

Appropriate time scale for aggregating climate data to predict flowering and boll setting behaviour of cotton in Egypt

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ABSTRACT

This study investigates the statistical relationship between weather variables and aspects of cotton yield production. The aim is to find the optimum interval between data for statistical correlation with a number of yield parameters. Two uniform field trials using the cotton cv. Giza 75 (*Gossypium barbadense* L.) were conducted at the Agricultural Research Center, Giza, Egypt. Randomly chosen plants were used to record daily numbers of flowers and bolls during the boll development stage (60 days). During this period, daily air temperature, temperature magnitude, evaporation, surface soil temperature, sunshine duration, humidity, and wind speed were recorded. Data grouped into intervals of 2, 3, 4, 5, 6, and 10 days were correlated with cotton production variables using regression analysis. Evaporation was found to be the most important climatic variable affecting flower and boll production, followed by humidity and sunshine duration. The least important variables were surface soil temperature at 0600 h and minimum temperature. The five-day interval was found to be more adequately and sensibly related to yield parameters.

Key Words: *cotton flower; boll production; boll retention; evaporation; humidity; sunshine duration; temperature.*

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 cotton plants 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

Abbreviations: PGR — *plant growth regulator*; TKW — *thermal kinetic window* 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.

Many factors, such as length of the growing season, climate (including solar radiation, temperature, light, wind, rainfall, and dew), cultivar, availability of nutrients and soil moisture, pests, and cultural practices affect cotton growth (El-Zik, 1980). The balance between vegetative and reproductive development can be influenced by soil fertility, soil moisture, cloudy weather, plant spacing, and perhaps other factors such as temperature and humidity (Guinn, 1982). Hodges et al. (1993) found that the optimum temperature for cotton stem and leaf growth, seedling development, and fruiting was almost 30°C, with fruit retention decreasing rapidly as the time of exposure to 40°C increased. Miller et al. (1996) reported that regression of yield with rainfall and temperature (data gathered during the period from 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 subject to management. Reddy et al. (1998) found that when Upland cotton (*G. hirsutum*) cv. DPL-51 was grown in naturally lit plant growth chambers at 30/22°C day/night temperatures from sowing until flower bud production, and at 20/12, 25/17, 30/22, 35/27 and 40/32°C for 42 days after flower bud production, fruit retention was severely curtailed at the two higher temperatures compared with 30/22°C. Species/cultivars that retain fruits at high temperatures would be more productive both in the present-day cotton production environments and even more in a future warmer world.

In Egypt, field studies relating cotton flower and boll production to climatic factors are lacking. The objective of this study was to collect information on responses in Egypt of field grown cotton plants to the climatic fluctuations during the production period (about 60 days) of flowering and boll setting. This information will provide a better understanding of the effect of climatic factors and determine the most important of these factors regarding their impact on cotton production and help producers to become better crop managers. Also, this study aimed at predicting effects of climatic factors during different convenient intervals (in days) on cotton flower and boll production compared with daily observations. The study presents a rich effort focused on evaluating the efficiency of regression equations between cotton crop data and climatic data grouped at different time intervals, to determine the appropriate time scale for aggregating climate data when it is to be used for predicting flower and boll production in cotton.

MATERIALS 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 consumptive during each of the two growing seasons supplied by surface irrigation was about 6,000 m^3 h^{-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 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 superphosphate during land 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 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 each ridge) from 9 and 11 inner ridges of the plot in Seasons I and II, respectively. 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), which would give sound bolls at the end of the handpicking 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 were not expected to form sound harvestable bolls, and therefore were not taken into account. Observations used in the statistical analysis were obtained during the entire production stage of flowering and boll development (60 days for each season, 29 June to 27 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 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 on each day in all selected plants] × 100).

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 humidity (%, X_8), minimum humidity (%, 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 2 growing seasons. Range and mean values of the climatic parameters (independent variables) recorded during the production stage for both seasons are listed in Table 1.

STATISTICAL ANALYSIS

Statistical analysis was conducted using the procedures outlined in the general linear model (GLM; SAS Institute, Inc., 1985). Data of dependent and independent variables, collected for each day of the production stage (60 days in each season), were summed up into intervals of 2, 3, 4, 5, 6, or 10 days. Data from these intervals were used to compute relationships between the dependent variables (flower and boll setting and boll retention) and the independent variables (climatic factors) in the form of simple correlation coefficients r for each season. Comparisons between the values of r were done to determine the best interval of days for determining effective relationships. The α-level for significance was $P \leq 0.15$. Those climatic factors attaining a probability level of significance not exceeding 0.15 were deemed important (affecting the dependent variables), selected, and combined with dependent variable in multiple regression analysis to obtain a convenient predictive equation (Cady and Allen, 1972). Multiple linear regression equations (using stepwise method) comprising selected predictive variables were computed for the determined interval, and coefficients of multiple determination (R^2) were calculated to measure the efficiency of the regression models in explaining the variation in data. Correlation and regression analyses were computed according to Draper and Smith (1966).

Table 1. Range and mean values of the independent variables (climatic factors) for the two seasons and the overall data.

Climatic factors	First season		Second season		Over all data (Two seasons)	
	Range	Mean	Range	Mean	Range	Mean
X_1: Max Temp (°C)	31.0-38.4	34.2	30.6-38.8	34.0	30.6-38.8	34.2
X_2: Min Temp (°C)	18.6-24.4	21.8	18.4-23.9	21.8	18.4-24.4	21.8
X_3: Max-Min Temp	9.4-18.3	12.4	8.5-17.6	12.3	8.5-18.3	12.3
X_4: Evap. (mm d^{-1})	7.6-15.2	10.0	4.1-9.8	6.0	4.1-15.2	8.0
X_5: 0600 h Temp (°C)	14.0-21.5	17.8	13.3-22.4	18.0	13.3-22.4	17.9
X_6: 1800 h Temp (°C)	19.6-27.0	24.0	20.6-27.4	24.2	19.6-27.4	24.1
X_7: Sunshine (h d^{-1})	10.3-12.9	11.7	10.3-13.0	11.8	10.3-13.0	11.8
X_8: Max Hum (%)	62-96	86.6	51-84	73.1	51-96	79.6
X_9: Min Hum (%)	17-45	31.0	23-52	39.7	17-52	35.3
X_{10}: Wind speed (m s^{-1})	ND[a]	ND	2.2-7.8	4.6	ND	ND

[a] ND—not determined

RESULTS AND DISCUSSION

Daily number of flowers and number of bolls per plant that survived to maturity (dependent variables) during the production stage of the 2 growing seasons (in Seasons I and II, respectively) are graphically illustrated in Figures 1 and 2. The flowering- and boll-curves reached their peaks during the middle 2 week 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 1) play an important role (Miller et al., 1996).

CORRELATION ESTIMATES

Simple correlation coefficients were estimated between the production variables and studied climatic factors for different intervals of days (combined data of the 2 seasons); see Table 2. According to these correlation coefficients, it could be seen that all significant relationships were negative except for the positive relationships between minimum humidity.

Evaporation was the most important climatic factor affecting flower and boll production in Egyptian cotton. The negative correlation means that high evaporation ratio significantly reduced flower and boll production. High evaporation rates could result in water stress that would slow growth and increase shedding rate of flower and boll production. Kaur and Singh (1992) found that flower number of cotton was decreased by water stress, particularly when applied at flowering. Seed cotton yield was decreased by about 50% when water stress was applied at flowering, slightly decreased by stress at boll formation, and not significantly affected by stress in the vegetative stage (6-7 weeks after sowing).

The second most important climatic factor was minimum humidity, which had a high positive correlation with flower and boll production, and retention ratio. The positive correlation means that increased humidity would bring about better boll production.

The third most important climatic factor in our study was sunshine duration, which showed a significant negative relationship with flower and boll production only.

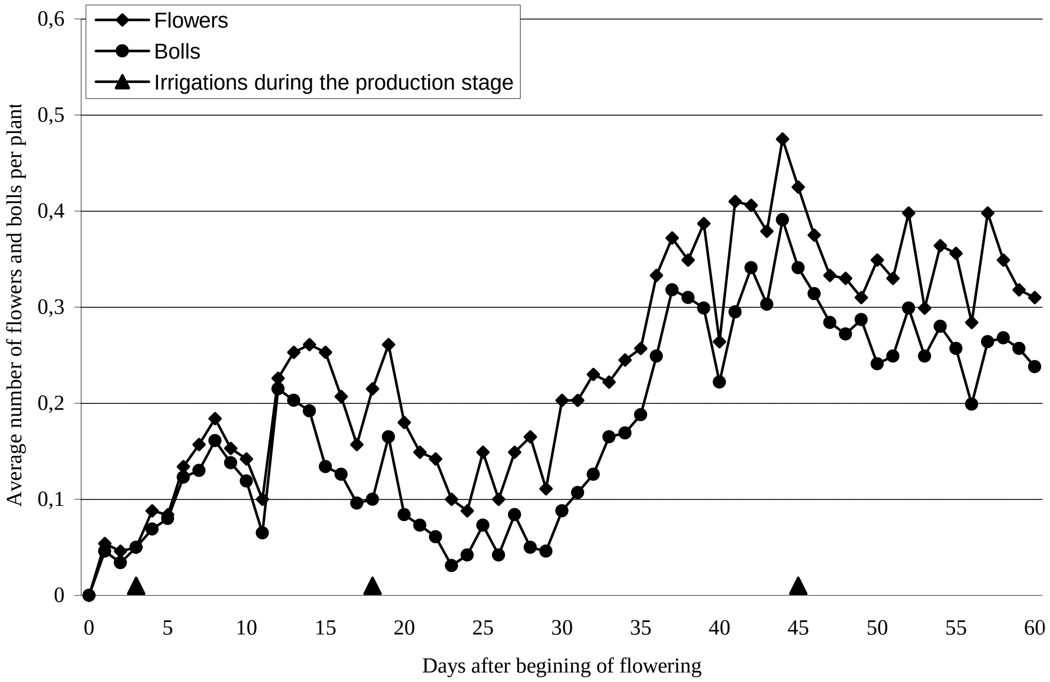

Figure 1. Daily number of flowers and bolls during season I (sample size was 261 plants).

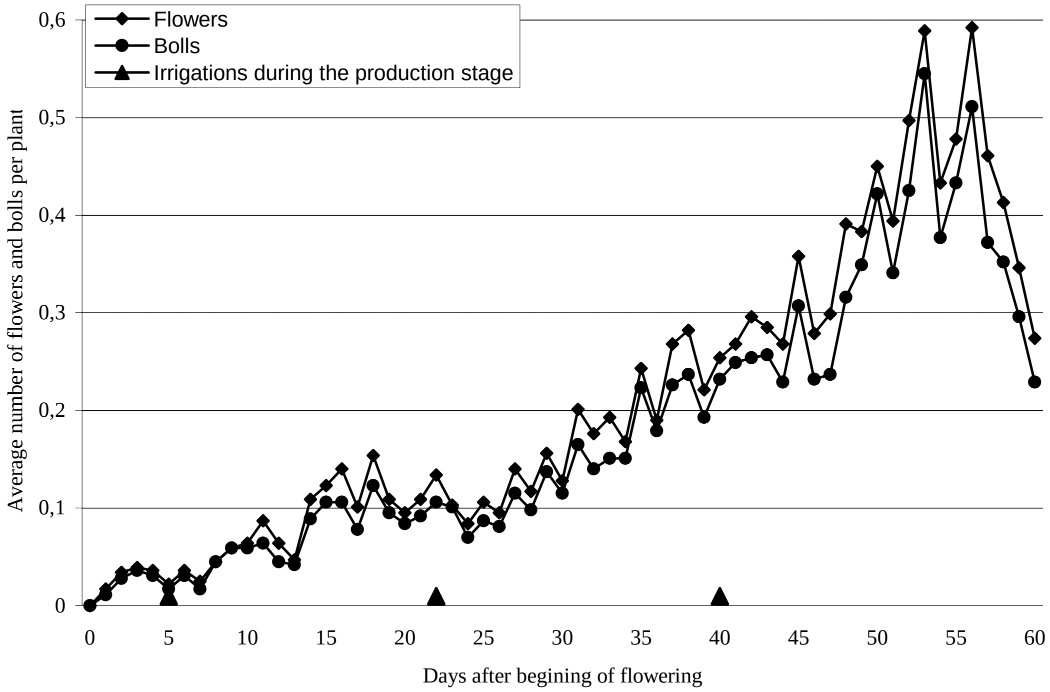

Figure 2. Daily number of flowers and bolls during season II (sample size was 358 plants).

Table 2. Simple correlation coefficient values between the production variables and the studied climatic factors for the daily and different intervals of days combined over both seasons.

Daily and intervals of days	Production variables	Climatic factors[a]								
		Air temp (°C)			Evap	Surface soil temp (°C)		Sunshine duration	Humidity (%)	
		Max (X_1)	Min (X_2)	Max-Min (X_3)	(mm d^{-1}) (X_4)	0600 h (X_5)	1800 h (X_6)	(h d^{-1}) (X_7)	Max (X_8)	Min (X_9)
Daily (n[b] = 120)	Flower	−0.15^{++}	NS[c]	−0.26**	−0.33**	NS	−0.20*	−0.23*	NS	0.30**
	Boll	NS	NS	−0.25**	−0.43**	NS	−0.19^{++}	−0.18^{++}	NS	0.36**
	Boll ret. rat.	NS	NS	NS	−0.56**	NS	NS	NS	NS	0.34**
2 Days (n = 60)	Flower	−0.31^{++}	NS	−0.32*	−0.36**	NS	−0.24^{+}	−0.36**	NS	0.37**
	Boll	−0.29^{++}	NS	−0.30^{++}	−0.46**	NS	−0.21^{+}	−0.31*	NS	0.44**
	Boll ret. rat.	NS	NS	NS	−0.61**	NS	NS	NS	NS	0.40**
3 Days (n = 40)	Flower	−0.34*	NS	−0.34*	−0.33*	NS	−0.28^{++}	−0.39*	NS	0.34*
	Boll	−0.32*	NS	−0.32*	−0.48**	NS	−0.24^{+}	−0.36*	NS	0.45**
	Boll ret. rat.	NS	NS	NS	−0.63**	NS	NS	NS	NS	0.40*
4 Days (n = 30)	Flower	−0.31^{++}	NS	−0.35^{++}	−0.33^{++}	NS	−0.28^{+}	−0.39*	NS	0.34^{++}
	Boll	−0.31^{++}	NS	−0.33^{++}	−0.48**	NS	−0.23^{+}	−0.38*	NS	0.45*
	Boll ret. rat.	NS	NS	NS	−0.64**	NS	NS	NS	NS	0.42*
5 Days (n = 24)	Flower	−0.35^{++}	NS	−0.37^{++}	−0.39^{++}	NS	−0.39^{++}	−0.52**	NS	0.41*
	Boll	−0.33^{+}	NS	−0.35^{++}	−0.49*	NS	−0.35^{++}	−0.44*	NS	0.47**
	Boll ret. rat.	NS	NS	NS	−0.66**	NS	NS	NS	NS	0.43*
6 Days (n = 20)	Flower	−0.37^{++}	NS	−0.41^{++}	−0.38^{++}	NS	NS	−0.54**	NS	0.42*
	Boll	−0.37^{++}	NS	−0.40^{++}	−0.49*	NS	NS	−0.46*	NS	0.49*
	Boll ret. rat.	NS	NS	NS	−0.69**	NS	NS	NS	NS	0.45*
10 Days (n = 12)	Flower	NS	NS	−0.45^{++}	−0.40^{+}	NS	−0.55*	−0.65*	NS	0.43^{++}
	Boll	NS	NS	−0.43^{++}	−0.51^{++}	NS	−0.53^{++}	−0.57*	NS	0.51^{++}
	Boll ret. rat.	NS	NS	NS	−0.74**	NS	NS	NS	NS	0.55*

[a] Wind speed did not show significant effect upon the studied production variables, so is not reported.

[b] n—Number of data pairs used in calculation.

[c] NS — Means simple correlation coefficient is not significant at the 15% probability level.

** Significant at $P < 0.01$, * Significant at $P < 0.05$, $^{++}$ Significant at $P < 0.1$, $^{+}$ Significant at $P < 0.15$.

The negative relationship between sunshine duration and cotton production may be due to the fact that the species of the genus *Gossypium* are known to be short day plants (Hearn and Constable, 1984). So, an increase of sunshine duration above that sufficient to attain good plant growth will decrease flower and boll production. Bhatt (1977) found that exposure to daylight over 14 hours and high day temperature, individually or in combination, delayed flowering of the Upland cotton cv. J34. Although average sunshine duration in our study was only 11.7 h, it did range up to 13 h, which, in combination with high maximum temperatures (up to 38.8°C), may have adversely affected reproductive growth.

Maximum air temperature, temperature magnitude, and surface soil temperature at 1800 h show significant negative correlation with flower and boll production only. Meanwhile, the least important factors were surface soil temperature at 0600 h and minimum air temperature. 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). Plant temperature above or below the TKW resulted in stress that limited 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 temperatures are within the TKW. Productivity of cotton, therefore, is strongly influenced by the relationship between plants TKW and the temperature crop experiences during the growing season.

Our results indicate that evaporation was the most effective climatic factor affecting cotton boll production. As the sign of the relationship was negative, this means that an increase in evaporation caused a significant reduction in boll number. Thus, applying specific treatments, such as an additional irrigation or the use of plant growth regulators (PGR) that would decrease the deleterious effect of evaporation after boll formation, could contribute to an increase in cotton boll production and retention, and consequently an increase in cotton yield. In this connection, Meek et al. (1999), in a field experiment in Arkansas, found that application of 3 or 6 kg glycin betaine (PGR) ha^{-1} to cotton plants under mild water stress increased yield.

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

REGRESSION MODELS

Multiple linear regression equations were estimated using the stepwise multiple regression technique to express the relation between cotton production variables (number of flowers (Y_1); bolls per plant (Y_2); and boll retention ratio (Y_3)) and the studied climatic factors (Table 3).

Evaporation, surface soil temperature at 1800 h, sunshine duration, and minimum humidity accounted for a highly significant amount of variation ($P \leq 0.05$) in cotton production variables, with the equation obtained for the 5-day interval showed a high degree of certainty. The R^2 values for the 5-day interval were higher than those obtained from daily data for each of the cotton production variables. Also, the 5-day interval gave more efficient and stable estimates than the other intervals studied (data not shown).

The R^2 values for these equations clearly indicate the importance of such equations since the climatic factors involved explained about 59 to 62% of the variation found in the dependent variables. Several workers, studying the effect of climatic factors on cotton boll production and retention and, in turn, yield, have found different relationships. Mergeai and Demol (1991) in phytotron trials in Belgium found that cotton yield was favoured by intermediate relative humidity (60%) and temperatures of 24-28°C. Under long photoperiods (16 h), low night temperature (12°C) increased vegetative growth and cotton yields, but under short photoperiods (12 h), yields were better with a higher night temperature (16°C).

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

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

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

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

** Significant at $P < 0.01$.

CONCLUSIONS

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. Collecting data at a 5-day interval will certainly reduce computational resources and give better results than obtained from the other intervals used in this study or daily records. 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, humidity, which had a positive correlation with boll production, was also an important climatic factor. In general, increased humidity would bring about better boll production. The least important climatic factors were surface soil temperature at 0600 h and minimum air temperature. The early prediction of adverse climatic factors could help in minimizing their deleterious effects through applying specific cultural practices. Finally, 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 used to forecast adverse effects on cotton production and, with the application of appropriate production practices, circumvent possible production shortage.

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