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Statistical Modelling for Cotton Yield Estimation Using Agricultural Climate Indices (A Case Study of Gharakhil District in Mazandaran Province, Iran)

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ABSTRACT
Because the climatic factors are largely uncontrolled, the variables that influence crop production must be quantitatively evaluated if we want to explain adequately the effects of any climatic variable on cotton growth stages. Cotton (*Gossypium hirsutum* L.) is a major row crop grown primarily for fiber and seed. The objective of this investigation was to develop Agroclimatic-Yield based regression models for estimation rain-fed cotton for Gharakhil district (Mazandaran Province, Iran) using available historical data. Twenty-Seven years (from 1985 to 2011) historical cotton yield data published by Gharakhil Agromet. Station (GAS) was related to climatological variables and agroclimatological indices to develop Agroclimate-Yield models. On the basis of correlation coefficient, F-statistics, standard error of estimate (r = 0.455, F = 4.431, SEOE = 894 kg ha^{-1} for Logarithmic regression model and r= 0.722, F= 5.456, SEOE= 739 kg ha^{-1} for Cubic regression model) and relative deviation (RD) of the selected years, the suitable time of estimation for cotton yield was found to be at the end of squaring stage i.e., July 19th (3 months before harvesting) using climatological and agroclimatological data/indices of the squaring stage (from June 28th to July 19th). The best agroclimatic subset were selected as Temperature Difference (TD) for Logarithmic and Rainfall (R) for Cubic model.

Key words: Agroclimatic regression models, rain-fed farming, yield estimation

INTRODUCTION
Because the climatic factors are largely uncontrolled, the variables that influence crop production must be quantitatively evaluated if we want to explain adequately the effects of any climatic variable on cotton growth stages. So, it is important to determine the most important climatic factors on increasing or decreasing cotton production and its magnitude (Sawan *et al*., 2002; Rao, 2003; Abbate *et al*., 2004; Yeates *et al*., 2010). Plant growth and yield are results of the interaction of weather that prevailed during crop growing period and genetic constitution of crop plants. Solar radiation, temperature, rainfall (amount and temporal distribution), relative humidity and wind velocity are considered as significant meteorological variables that influence growth, development as well as yield of crops (Meena and Dahama, 2004; Reddy and Reddi, 2003).

Cotton (*Gossypium hirsutum* L.) as a major row crop is grown chiefly for fiber and seed. It is primarily grown in dry tropical and subtropical climates at temperatures between 11 and 25°C. Heat or freezing temperatures threaten the crop in warm climate; although its resistance varies depending on its species. Cotton requires an average annual temperature of over 16°C and an annual rainfall of about 500 mm distributed throughout the growing season. A daily minimum temperature of 15°C required for germination and 21-27°C for proper vegetative growth (Reddy *et al*., 1992a; Pettigrew, 2004). The prevalence of high temperatures (greater than 35.8°C) and rapid soil drying during peak flowering and fruiting later in the season, can also substantially reduce cotton production (Boyer, 1982; Singh *et al*., 2006; Ghaderi *et al*., 2006), in Gorgan, located in the Caspian sea shore, Iran, showed that daily temperature more than 32°C can cause cotton crop under stress during squaring and boll formation and hence reduction in yield.

Silvertooth (2001) reported that early bloom, peak bloom and cut-out are major stages in cotton crop development. He also realized that the period between first bloom and cut-out is the time of the highest potential in the crop yield, either gained or lost. The effect of agrometeorological factors (rainfall, temperature sum, air humidity deficits and relative air humidity) on the cotton fiber fineness was studied by Stoilova and Nikolov (2000) on the basis of ten-year field trials conducted in 1987-1998. They found that the correlation between the metric number of fiber and deficits in air humidity in September and especially during the second ten days of this month was the strongest expressed ($r = 0.922$ and 0.944).

Photosynthesis and the supply of photosynthate are reduced by environmental conditions, like rainy weather, water deficits and high temperatures and this process increases square and boll shed (Guinn, 1998). The essential factors to ensure the appropriate seed germination and crop appearance are proper soil temperature and moisture conditions. Insufficient water plays the most important role in limitation of plant survival and crop productivity. Cotton is grown on all types of soils like sandy loam, clay loam, black cotton soil, alluvial soil and lateric soils. Elements such as fertile soil and suitable moisture capacity are necessary for cotton.

Bauer *et al*. (1984) stated that among the environmental factors the primary contributing element of plant development rate is temperature. Cotton requires a minimum daily air temperature of 15°C for germination, 21-27°C for vegetative growth and 27-32°C during the fruiting period. Cotton approximately needs 150 days above 15°C during growth period (Waddle, 1984; Reddy, 1996). The least necessary quantity of water to produce a cotton crop is 500 mm (rainfall and/or irrigation). It is essential for cotton to have degrees of rainfall and/or irrigation between 550 and 950 mm during a season in a constant and normal pattern (Doorenbos and Pruitt, 1984). The duration of each phase differs, depending on the species, diversities, weather conditions and the followed cultivation techniques, as well. Table 1 shows the

Table 1: Average phenological stages of cotton crop for Gharakhil district used for different agroclimatic-yield models

Crop cotton growth stages	Date	Duration (days)
Germination	16 to 20 May	15
Emergence	21 May to 1 June	11
Three leaf formation	2 to 27 June	26
Squaring	28 June to 19 July	22
Flowering	20 July to 10 Sep.	53
Boll opening	11 to 28 Sep.	18
Ripening	29 Sep. to 22 Oct.	24
Cotton growth period	16 May to 22 Oct.	169

approximate number of days and growing degree-days (GDD) during growth stages of cotton (FAO, 2012). The objective of this investigation was to develop Agroclimatic-Yield based regression models for estimation cotton yield for rain-fed farming in Gharakhil district (Mazandaran Province, Iran) using available historical data.

MATERIALS AND METHODS

Study area: Cotton yield estimation using Agroclimatic based models was conducted for Gharakhil district of the Mazandaran Province which is located in Caspian sea shore in North of Iran. The climate of district is of typically humid with moderately warm summer and cold winter. Rice, cotton and citrus are important crops. Cotton is sown from first to third week of May. The crop reaches flowering stage around end of July and harvesting commences during October month. The crop growth duration is about 150-170 days.

Methodology for cotton yield estimation: An attempt was made to develop Agroclimatic-Yield based models for rain fed cotton for Gharakhil district (Mazandaran Province) using available historical data. Twenty-Seven years (from 1985 to 2011) historical yield data published by Gharakhil Agromet. Station(GAS) was related to climatological variables and agroclimatological indices to develop Agroclimate-Yield models (Table 2).

The procedure for calculation of agroclimatic indices are not given due to brevity. For more details, readers are requested to see Bazgeer *et al.* (2006), Hundal *et al.* (1997) and Nuttonson (1955).

Cotton phenological stages: To integrate various agroclimate indices over different growth phases, cotton growing season was divided into seven phenological stages, starting from the sowing of crop on 16th of May up to harvesting on 22nd of October (Table 1). This was done based on average of 26 years data studied in Gharakhil Agromet. Station.

Agroclimatological statistical models: Different climatological variables and agroclimatological indices were used to develop agroclimate-yield models for each crop phenological stages. Daily climatological data (1985-2011) from Gharakhil Agromet Station (GAS) were used for this purpose. Regression models were established using the stepwise simple/multiple regression technique to find the relationship between the agroclimatological data/indices and different cotton phenological growth phases using SPSS Softwares. Normal distribution frequency histogram was checked before undertaking the analysis for the climatic and agroclimatic data/indices and there was no need for data transformation. These data/indices were checked for collinearity and it was found from their low correlation values among these variables that there was no problem of multicollinearity.

Model validation: In order to evaluate the accuracy of different cotton yield models, estimated yield (Y_e) for the years 1985, 1988, 1991, 1992, 1997, 2000, 2005 and 2008 were compared with

Table 2: Climatological variables together with Agroclimatological indices used in cotton yield models (1985-2011)*

Parameters	Discription
Climatological variables	Maximum and minimum temperature, relative humidity, sunshine hours, rainfall, evaporation
Agroclimatological indices	Growing Degree-Days (GDD)**, Temperature Difference (TD), Photothermal Units (PTU), Heliothermal Units (HTU), Vapour Pressure Deficit (VPD)

* The climatological data collected at Gharakhil Agromet. Station were used for deriving above indices, ** A base temperature of 15°C was selected to determine GDD for different growth stages of Cotton (Waddle, 1984; Reddy *et al.*, 1992b)

corresponding observed/actual (Y_a) yield using Relative Deviation (RD) as a measure of estimated accuracy. It should be mention that these years were not used for model development:

$$RD = \frac{Ye - Ya}{Ya} \times 100 \quad (1)$$

RESULTS AND DISCUSSION

Various possible ways using climatological variables/agroclimatological indices for cotton yield modeling have been attempted. The simple and multiple linear and simple non-linear regression models have been developed to estimate cotton yield at different growth stages. In conformity with examination of F-Statistic, correlation coefficients (r), standard error of estimate (SEOE) as well as Relative Deviation (RD) values resulted from different agroclimate models, the best agroclimatic subset were selected to develop agroclimatic-yield models for Gharakhil district, Mazandaran Province. The yield-climate regression models at different growth stages will be discussed in the following section.

Germination: Sunshine hours were significantly correlated with cotton yield at germination stage among climatological variables. The regression models were Exponential, Logarithmic and Power (Table 3). The best model was power model with correlation coefficient of 0.528 at 5 percent level of significance. Kerby *et al*. (1987) reported that viability of cotton seed for planting is guaranteed on the basis of warm germination. Therefore, positively significant relationship between sunshine hours and cotton yield could be due to the effect of sunshine hours on increasing air temperature and hence soil temperature.

Squaring: Temperature difference and rainfall were significantly correlated with cotton yield at squaring stage among climatological variables. The regression models were logarithmic and cubic (Table 4). Between these models the best model was cubic with correlation coefficient of 0.722 at 1% level of significance.

Ripening: It was found that minimum temperature was the most important climatic factors which significantly effects cotton yield at ripening stage. The regression models were exponential, power, quadratic and cubic (Table 5). Among these models the best models were cubic and quadratic with

Table 3: Different regression models for cotton yield estimation at germination stage

Model	Equation	n	r	F-value	p-value	SEOE
Exponential	Ln(y) = 6.9980+0.108(SH)	19	0.508	5.927	0.026*	0.445
Logarithmic	Ln(y) = 1137.9+707 ln(SH)	19	0.469	4.800	0.043*	886.520
Power	Ln(y) = 6.9647+0.410 ln(SH)	19	0.528	6.585	0.020*	0.439

*Significant at 5% level, y: Cotton yield, SH: Sunshine hours, SEOE: Standard error of estimate

Table 4: Different regression models for cotton yield estimation at squaring stage

Model	Equation	n	r	F-value	p-value	SEOE
Logarithmic	y = 20554.5- 3518.1ln (TD)	19	0.455	4.431	0.050*	894.13
Cubic	$y = -0.038(R)^3+4.61(R)^2-104.4(R)+2426.08$	19	0.722	5.456	0.010**	739.06

*Significant at 5% level, ** Significant at 1% level, y: Cotton yield, TD: Temperature difference, R: rain, SEOE: Standard error of estimate

Table 5: Different regression models for cotton yield estimation at ripening stage

Model	Equation	n	r	F-value	p-value	SEOE
Exponential	$Ln(y) = 9.842-0.146 (T_{min})$	19	0.530	6.643	0.020*	0.438
Power	$Ln(y) = 13.374-2.117 \ln (T_{min})$	19	0.499	5.641	0.030*	0.448
Quadratic	$y = -116..3 (T_{min})^2+3408.9 (T_{min})-22279.0$	19	0.575	3.958	0.040*	846.380
Cubic	$y = -2.48 (T_{min})^3+1610.31 (T_{min})-13093.03$	19	0.575	3.945	0.040*	846.860

*Significant at 5% level, y: Cotton Yield, T_{min}: Minimum temperature, SEOE: Standard error of estimate

Table 6: RD values (%) for performance evaluation of agroclimatic-yield models at different growth stages of cotton for the selected years, Gharakhil District, Mazandaran Province

Growth stages	Germination			Squaring			Ripening		
Model*	M_e	M_l	M_p	M_l	M_c	M_e	M_p	M_q	M_c
1985	-30	-34	-36	-25	-53	-37	-38	-36	-35
1988	39	22	20	17	107	-7	-8	19	20
1991	91	79	73	7	52	28	28	73	75
1992	233	265	240	342	159	345	350	216	218
1997	40	43	36	52	101	-0.6	-0.6	36	38
2000	59	100	75	83	92	130	127	169	169
2005	-62	-67	-68	-32	-44	-57	-55	-52	-51
2008	-37	-23	-31	-13	-36	-35	-35	-11	-11

M_e, M_l, M_p, , M_q, M_c, are exponential, logarithmic, power, quadratic and cubic models, respectively. It should be mention that these years were not used for model development

correlation coefficient of 0.575 at 5% level of significance. Lomas *et al.* (1977), weekly maximum temperatures accounted for 28% and weekly minimum temperatures for 14% of the variability of cotton yields.

On the basis of results from different agroclimatic regression models, cotton yield was significantly correlated with sunshine hours (at germination stage), temperature difference and rainfall (at squaring stage) and minimum temperature (at ripening stage). In order to evaluate model validity, model estimated cotton yields were compared with corresponding observed/actual yield using relative deviation values (RD) for the years 1985, 1988, 1991, 1992, 1997, 2000, 2005 and 2008 (Table 6). These years were not used for model development.

According to RD values, the suitable time of estimation for cotton yield was found to be at the end of squaring stage i.e., July 19th (3 months before harvesting) using climatological and agroclimatological data/indices of the squaring stage (from June 28th to July 19th, Table 1). Climatological and agroclimatological data/indices used for this phenological stage of cotton growth were temperature difference (Logarithmic model) and rainfall (Cubic model). The regression models and their statistics in squaring phase are presented in Table 4.

The results revealed that temperature difference showed a negative relationship with cotton yield in logarithmic model. It means the more difference between maximum and minimum temperatures, the less will be cotton yield. Reddy *et al.* (1992a, b), pointed out temperature optimum for fruiting branch growth and square and boll production and retention was 30/22°C day/night temperature cycles. Above 30/22°C, there was an imbalance between vegetative and reproductive growth. Plants became less reproductive at 35/27°C and lost their reproductive ability at 40/32°C. Mauney (1986) also stated that all processes leading to square, blossom and boll initiation and maturation are temperature-dependent. Cool nights are beneficial during the

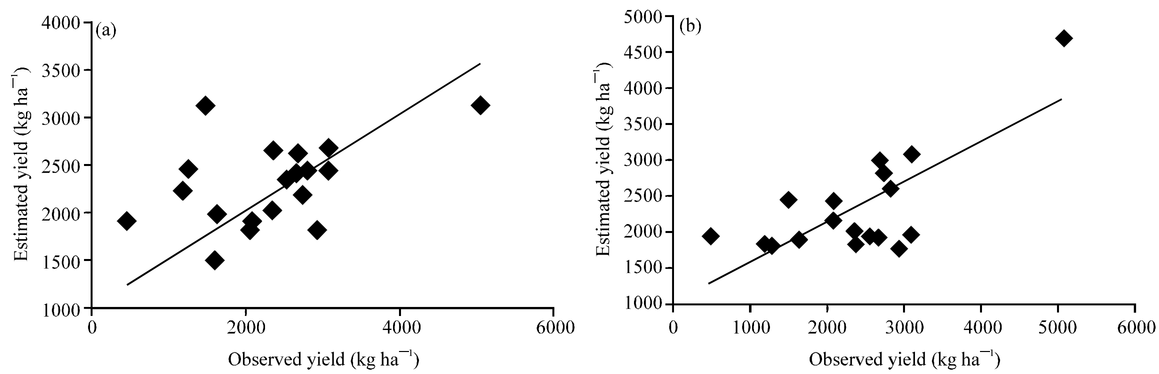

Fig. 1(a-b): Relationship between estimated and observed cotton yield using (a) Logarithmic and (b) Cubic regression models in squaring growth stage

fruiting period, but extremes in temperature (low or high) can result in delayed growth and aborted fruiting sites.The results also showed that there was a significant relationship between rainfall and cotton yield in squaring phase (r = 0.722, Cubic model). Cull *et al.* (1981) studied the effects of rainfall on the cotton yield. They figured out that the crop needs a lot of moisture as the plant moves into the squaring and setting boll stages and the main effect was associated with later rains which influenced the number of boll set.

On the basis of results the agroclimate-yield models explained 21 and 52% of yield variability due to variations in Temperature Difference (TD) and Rainfall (R) in logarithmic and cubic models, respectively (in squaring stage, June 28th to July 19th). Figure 1, presents the relationship between estimated and observed cotton yield using logarithmic and cubic regression models in squaring growth stage.

CONCLUSION

It could be concluded that from the results obtained in the present study, sunshine hours in germination stage, temperature difference and rainfall in squaring and minimum temperature in the ripening growth stage were the most significant climatic and/or agroclimatic factors influencing cotton crop. On the basis of correlation coefficient, F-statistics, standard error of estimation (r = 0.455, F = 4.431, SEOE = 894 kg ha^{-1} for Logarithmic regression model and r = 0.722, F = 5.456, SEOE = 739 kg ha^{-1} for Cubic regression model) and Relative Deviation (RD) of the selected years in model validation step, the suitable time of estimation for cotton yield was found to be at the end of squaring stage i.e., July 19th (3 months before harvesting) using climatological and agroclimatological data/indices of the squaring stage (from June 28th to July 19th). The best agroclimatic subset were selected as Temperature Difference (TD) for Logarithmic and Rainfall (R) for Cubic model.

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