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EFFECTS OF MULTI-TIME SCALES CLIMATE CHANGES ON TOBACCO-PLANTING COUNTIES IN CHENZHOU CITY OF HUNAN PROVINCE

Daiwei Pan, Quan Zhong[1], Yahua Liao[2], Bin He[1], Wujin Li[1], Hong Jian[1], Zhihong He[1], Zhihui Cao[1] and Yansong Xiao[1*]

Institute of Soil Science, Chinese Academy of Sciences, Nanjing, Jiangsu, China

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Abstract

To provide scientific instruction in predicting the climate changes and adopting the suitable measures for field cultivation and management of tobacco, the changes of main climatic parameters on multi-time scales in the six tobacco-planting counties of Chenzhou city in China were studied. Sunshine hours (S) in the six counties had significant positive linear correlation with year (from 1980 to 2020) and precipitation (P) changed irregularly on the scales of year, field-growth period, and rooting and flourishing stages, and they changed significantly in maturing stage. Sunshine hours (S) in the six counties had significant positive linear correlation with year on the scale of rooting stage, changed irregular with year on the scale of year, and showed different change tendencies in different counties in flourishing and maturing stages. On the scale of field-growth period, the daily cumulative temperature (T) was lower than the optimal value in rooting and flourishing stages, but higher than the optimal value in maturing stage.

Introduction

As the most typical region of Nanling hill ecological zone of tobacco-planting with the aroma style of burnt-pure sweet in China (Luo *et al*. 2019), Chenzhou City is the largest tobacco-planting region in Hunan province, accounting for about 1/3 (2.67×10^4 hm^2) of the total tobacco-planting area in Hunan (Luo *et al*. 2017).

Climate conditions influence or even determine the growth, yield and quality of tobacco ((Li 2000, Jin *et al*. 2009, Peng *et al.* 2009, Song 2010, Wu *et al*. 2011, Li *et al*. 2015). The previous studies related with tobacco-growth in Chenzhou City showed that, according to the optimal values of climate parameters for the planting of the high-quality tobacco, the temperature there was feasible but the sunshine hour was unsuitable a bit in tobacco field-growth period, and the precipitation was unfavorable in rooting stage but suitable in flourishing and maturing stages (Rong 2013). Low temperature and less sunlight hours in early growth stages and high temperature in maturing stage were the major factors for the occurrence of “high temperature forced early-maturity” (Kuang 2009). which could weaken the quality and the aroma style of tobacco (Chen *et al.* 2015a, 2015b). Different climate parameters changed differently at different time scales (year, tobacco field-growth period and growth stage), and sunshine hour and precipitation changed negatively while precipitation changed positively in maturing stage for tobacco growth (Kong *et al*. 2020).

But the above reports seldom considered the changes of climate parameters with time (Kuang 2009, Rong 2013, Chen *et al.* 2015a, 2015b), or only focused on one tobacco-planting counties in Chenzhou City (Chen *et al.* 2015b, Kong *et al*. 2020), little information so far is available on the changes of climate parameters with multi-time scales or in other tobacco-planting counties. Therefore, in this study the climate data from 1980 to 2020 of the all tobacco-planting counties in

*Author for correspondence: <35149517@qq.com>. [1]Chenzhou Tobacco Company of Hunan Province, Chenzhou, Hunan, China. [2]Hunan Provincial Tobacco Company, Changsha, Hunan, China.

Chenzhou City were used to analyze the characteristics, changes and tobacco-planting suitability of main climate parameters on different scales of time (year, tobacco field-growth period and growth stage) in order to help the prediction of climate changes and the adoption of suitable measures for field cultivation and management of tobacco.

Methods and Materials

Chenzhou City is located in the southeast of Hunan province, between 112˚13' to 114˚14' in east longitude and 24˚53' to 26˚50' in north latitude with a total area of 1.94 × 10^4 km^2, which belongs to subtropical monsoon humid climate with annual mean temperature of 15.4~18.3°C, cumulative sunshine hrs of 1510.3~1764.3 hrs, precipitation of 1320.3~1654.7 mm and frost-free season of 235~296 d (Rong 2013). The altitude of Chenzhou City ranges from 70 to 2061 m, and the landform is complex, varies with mountains and hills accounting for about 3/4 of the total area. The main soil types are red soil, yellow red soil and paddy soil (Hunan Agriculture Department 1989), and the total area of cultivated land is 30.96 × 10^4 hm^2 with the areas of 25.94 × 10^4 hm^2 of paddy fields and 5.02 × 10^4 hm^2 for dry fields (Chenzhou Municipal Bureau of Statistic 2018). Tobacco is mainly cultivated in paddy fields under the tobacco-late rice rotation.

The climate data from January 1 of 1980 to July 31 of 2020 which include daily cumulative sunshine hours (S), daily mean temperature (T) and daily cumulative precipitation (P) were collected from the national meteorological stations in the six tobacco-planting counties in Chenzhou City (Table 1).

Tobacco field-growth period in Chenzhou City is generally from March 10 to July 20, in which the rooting, flourishing and maturing stages are from March 10 to April 20, from April 21 to May 30 and from June 1 to July 20, respectively (Yu and He 2006, Xiao *et al.* 2007).

For data processing, statistical analysis and modeling IBM Statistics SPSS 20.0 were used (Xie *et al.* 2006).

Table 1. Information of national meteorological stations in six tobacco-planting counties in Chenzhou city.

Station number	County	Longitude	Latitude	Altitude (m)
57881	Anren (AR)	113°15'31"	26°42'50"	101.8
57973	Guiyang (GY)	112°43'29"	25°44'58"	329.1
57974	Jiahe (JH)	112°21'55	25°34'53"	214.5
57978	Linwu (LW)	112°32'47	25°16'23"	292.0
57976	Yizhang (YZ)	112°56'26	25°24'21"	222.8
57887	Yongxing (YX)	113°06'52	26°07'37"	167.6

Results and Discussion

The statistical information of S, T and P on different scales of time is presented in Table 2. For the six tobacco-planting counties in Chenzhou City, on the scale of year, S ranged from 1407 to 1534 hrs with a mean of 1463 hrs, T was from 17.7 to 18.7°C with a mean of 18.2°C, and P was from 1413 to 1511 mm with a mean of 1465 mm. On the scale of field-growth period, S was from 488 to 595 hrs with a mean of 545 hrs, T was from 21.6 to 22.2℃ with a mean of 22.0℃, and P was from 758 to 827 mm with a mean of 800 mm. On the scale of rooting stage, S was from 82 to 113 hrs with a mean of 96 hrs, T was from 14.9 to 15.8℃ with a mean of 15.4℃, and P was from

227 to 250 mm with a mean of 240 mm. On the scale of flourishing stage, S was from 138 to 174 hrs with a mean of 155 hrs, T was from 21.8 to 22.6℃ with a mean of 22.3℃, and P was from 258 to 275 mm with a mean of 265 mm. On the scale of the maturing stage, S was from 290 hes to 309 hrs with a mean of 294 hrs, T was from 26.7 to 27.8℃ with a mean of 27.3℃, and P was from 269 to 314 mm with a mean of 294 mm.

Table 2. Statistical descriptions of main climate parameters on different scales of time. (n=40)* (AR, GY, JH, LW, YZ and YX have been explained in Table 1).

Time scale	County	S (h)			T (℃)			P (mm)		
		Range	Mean±Sd	C.V. (%)	Range	Mean±Sd	C.V. (%)	Range	Mean±Sd	C.V. (%)
Year	AR	1189-1782	1453±156	10.72	16.9-19.4	18.2±0.6	3.29	913-2177	1511±311	20.58
	GY	1178-1840	1534±162	10.59	16.2-18.8	17.7±0.7	3.66	1023-2095	1487±245	16.50
	JH	981-1864	1407±196	13.93	17.3-19.4	18.4±0.5	2.86	967-2063	1413±252	17.82
	LW	1080-2027	1529±218	14.25	16.8-18.9	18.1±0.5	2.62	942-2137	1454±293	20.15
	YZ	1086-1732	1431±139	9.69	17.4-19.7	18.7±0.6	3.00	1002-1897	1453±233	16.05
	YX	1202-1685	1425±122	8.59	16.7-19.0	18.1±0.6	3.20	923-2253	1473±278	18.86
Field period	AR	338-693	556±78	14.05	20.6-23.8	22.1±0.7	3.38	442-1293	821±214	26.02
	GY	380-769	595±79	13.29	20.1-23.3	21.6±0.8	3.62	499-1247	789±166	20.97
	JH	357-303	538±107	19.85	20.7-23.7	22.2±0.7	3.04	451-1234	758±156	20.60
	LW	303-904	541±124	22.93	20.4-22.9	21.8±0.6	2.93	516-1231	827±171	20.67
	YZ	314-611	488±68	13.98	20.8-23.7	22.2±0.7	3.20	500-1205	811±161	20.17
	YX	355-695	550±66	12.06	20.4-23.3	21.9±0.7	3.24	444-1325	794±180	22.67
Rooting stage	AR	45-185	96±32	33.27	10.8-18.3	15.1±1.6	10.68	92-531	248±96	38.58
	GY	36-215	113±39	34.86	10.2-18.1	14.9±1.7	11.59	94-540	250±91	36.54
	JH	33-190	95±39	40.91	11.3-18.7	15.7±1.6	10.30	82-446	227±83	36.84
	LW	23-238	96±49	51.26	11.4-18.3	15.6±1.5	9.63	76-477	228±96	41.88
	YZ	33-172	82±31	37.78	11.7-18.8	15.8±1.5	9.60	77-527	240±97	40.42
	YX	36-192	95±34	36.47	11.1-18.1	15.2±1.5	10.00	113-477	246±87	35.54
Flourishing stage	AR	97-241	163±36	22.23	20.5-25.1	22.4±1.0	4.33	98-538	259±97	37.34
	GY	92-249	174±39	22.45	19.9-24.5	21.8±1.0	4.55	108-477	258±81	31.41
	JH	68-256	152±47	31.01	20.7-25.1	22.6±0.9	4.10	118-409	263±70	26.47
	LW	72-375	152±57	37.36	20.5-24.7	22.1±0.9	3.99	143-494	275±84	30.01
	YZ	85-211	138±32	23.08	20.9-24.9	22.5±0.9	4.02	121-441	275±84	30.45
	YX	91-219	153±34	22.10	20.2-24.6	22.1±0.9	4.27	125-495	258±74	28.81
Maturing stage	AR	168-415	297±57	19.26	26.2-29.6	27.8±0.8	2.83	58-757	314±162	51.56
	GY	181-438	309±56	18.01	25.1-29.1	27.0±0.8	2.86	58-619	282±124	44.05
	JH	174-402	291±60	20.70	25.7-29.6	27.5±0.7	2.68	68-515	269±113	42.12
	LW	151-410	294±54	18.52	25.2-28.3	26.7±0.6	2.31	113-652	314±133	42.48
	YZ	120-641	297±120	40.38	25.6-29.2	27.3±0.7	2.47	120-641	297±120	40.38
	YX	77-796	290±149	51.27	25.7-29.2	27.4±0.8	2.84	77-796	290±149	51.27

*The significance of differences in the same climate parameter between different regions was not marked in the Table because the emphasis of this study is on the changes of climate parameters and the assessment on tobacco-growth suitability and the possible difference in a same climate parameter between the six tobacco-planting counties is naturally attributed to the spatial distribution.

Sunshine hours showed moderate variation in most cases (C.V.(%) was 10~100%, Table 2) except in weak variation (C.V.(%) was < 10%, Table 2). In YZ and YX on the scale of year, T were mostly in weak variation except in moderate variation in LW and YZ on the scale of rooting stage, while P were all in moderate variation on all the scales of time. The variation of P was the largest, followed by S and T, C.V. (%) of S, T and P ranged from 16.05~20.58%, 8.59~14.25% and 2.62~3.66% with the mean of 18.33, 11.30 and 3.11%, respectively on the scale of year, from 20.17~26.02%, 12.06~22.93% and 2.93~3.62% with the mean of 21.85, 16.03 and 3.24%, respectively on the scale of field period, from 35.54~41.88%, 33.27~51.26% and 9.60~11.59% with the mean of 38.30, 39.09 and 10.30%, respectively on the scale of rooting stage, from 26.47~37.34%, 22.10~37.36% and 3.99~4.55% with the mean of 30.75, 26.37 and 4.21%, respectively on the scale of flourishing stage, from 40.38~51.56%, 17.70~20.70% and 2.31~2.86% with the mean of 45.31, 19.02 and 2.67%, respectively on the scale of maturing stage.

Table 3 shows Pearson correlation coefficients of S, T and P with time on the scales of year, tobacco field-growth period and different growth stages. It can be seen that T changed more regularly than S and P because T had significant positive correlation on the scale of year, tobacco field-growth period, rooting and flourishing stages. On the scale of year, in all counties, T had significant positive correlation with year ($p = 0.000$), while S and P had no significant correlation with year ($p = 0.063$~0.830 for S and 0.313~0.865 for T). On the scale of field-growth period, T still had significant positive correlation with year ($p = 0.000$) and P still had no significant positive correlation with year ($p = 0.182$~0.650), while S had positive correlation with year only in LW ($p = 0.014$). On the scale of rooting stage, both S and T had significant positive correlation with year ($p = 0.000$~0.002 for S and 0.000 for T), while P had no significant correlation with year ($p = 0.148$~0.675). On the scale of flourishing stage, S, T and P showed the similar change tendencies as on the scale of field-growth period, T still had significant positive correlation with year ($p = 0.001$~0.009) and P still had no significant positive correlation with year (0.271~0.981), while S had positive correlation with year in only LW ($p = 0.035$). On the scale of maturing stage, S had significant negative correlation with year in AR, YZ and YX ($p = 0.023$, 0.017 and 0.001, respectively), T had significant positive correlation with year only in YZ ($p = 0.014$), while P had significant positive correlation with year in AR, JH and YZ ($p = 0.020$, 0.029 and 0.024, respectively).

Table 4 shows the optimal regression models of climate parameters on different scales of time which were obtained with the module of Curve Estimation in SPSS software. It can be seen that the linear regression model could describe well the changes of the climate parameters on different scales of time. Meanwhile, the accuracy was the highest for the climate models on the scale of year (R^2 was 0.453~0.663 with a mean of 0.584 and $p = 0.000$), followed by the climate models on the scale of field period (R^2 was 0.145~0.591 with a mean of 0.473 and $p = 0.000$~0.014), and the climate models had the lowest accuracy on the scale of growth stage (R^2 was 0.117~0.245 with a mean of 0.146 and $p = 0.001$~0.029). On the other hand, the accuracies of the climate models were higher in rooting stage (R^2 was 0.212~0.468 with a mean of 0.363 and $p = 0.000$~0.002 with a mean of 0.000) than those in flourishing and maturing stages (R^2 was 0.109~0.265 with a mean of 0.187 and 0.117~0.245 with a mean of 0.146, $p = 0.001$~0.035 with a mean of 0.009 and 0.001~0.029 with a mean of 0.018).

The optimal temperature for tobacco growth is 25~28℃ (Xiao *et al.* 2006). As shown in Table 2, in the six counties in Chenzhou City, Temperature in rooting stage (14.9~15.8℃) and in flourishing stage (21.8~22.5℃) was lower than the optimal value, but T was higher than the optimal value in maturing stage (28.3~29.6℃). The optimal sunshine hour and precipitation for tobacco growth is 500~700 hrs (Xie *et al.* 2006) and 700~800 mm (Yang *et al.* 1987) in field-growth period. It has been found that , in the six counties in Chenzhou City, S was 488 hrs in YZ, lower than the optimal values (Table 2), but S in other counties (538~595 hrs), was within

Table 3. Pearson correlation coefficients between main climatic parameters with year (n=40). (S, T, P, AR, GY, JH, LW, YZ and YX as mentioned in the text and Table 1).

	Parameter	Correlation	AR	GY	JH	LW	YZ	YX
Year	S	Pearson correlation coefficient	0.035	0.121	0.073	0.297	-0.034	-0.161
		Sig. (2-tailed)	0.830	0.456	0.656	0.063	0.837	0.322
	T	Pearson correlation coefficient	0.797**	0.799**	0.673**	0.706**	0.785**	0.814**
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	P	Pearson correlation coefficient	0.113	0.048	0.096	0.164	0.029	-0.028
		Sig. (2-tailed)	0.486	0.770	0.558	0.313	0.860	0.865
Whole field period	S	Pearson correlation coefficient	-0.038	0.261	0.064	0.381*	-0.047	-0.158
		Sig. (2-tailed)	0.812	0.100	0.690	0.014	0.769	0.323
	T	Pearson correlation coefficient	0.736**	0.769**	0.669**	0.698**	0.745**	0.736**
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	P	Pearson correlation coefficient	0.131	0.093	0.213	0.228	0.120	0.073
		Sig. (2-tailed)	0.414	0.561	0.182	0.151	0.456	0.650
Rooting stage	S	Pearson correlation coefficient	0.533**	0.647**	0.555**	0.636**	0.461**	0.549**
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.002	0.000
	T	Pearson correlation coefficient	0.684**	0.666**	0.626**	0.550**	0.598**	0.658**
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	P	Pearson correlation coefficient	-0.230	-0.158	-0.068	-0.077	-0.082	-0.183
		Sig. (2-tailed)	0.148	0.323	0.675	0.634	0.612	0.253
Flourishing stage	S	Pearson correlation coefficient	0.010	0.138	0.052	0.330*	0.066	-0.090
		Sig. (2-tailed)	0.951	0.390	0.748	0.035	0.682	0.576
	T	Pearson correlation coefficient	0.401**	0.433**	0.501**	0.393*	0.514**	0.430**
		Sig. (2-tailed)	0.009	0.005	0.001	0.011	0.001	0.005
	P	Pearson correlation coefficient	-0.087	-0.168	-0.047	0.004	-0.176	0.063
		Sig. (2-tailed)	0.589	0.294	0.770	0.981	0.271	0.695
Maturing stage	S	Pearson correlation coefficient	-0.355*	-0.185	-0.287	-0.051	-0.370*	-0.495**
		Sig. (2-tailed)	0.023	0.248	0.069	0.749	0.017	0.001
	T	Pearson correlation coefficient	0.269	0.300	0.100	0.283	0.380*	0.298
		Sig. (2-tailed)	0.089	0.057	0.533	0.074	0.014	0.059
	P	Pearson correlation coefficient	0.361*	0.271	0.342*	0.307	0.352*	0.282
		Sig. (2-tailed)	0.020	0.086	0.029	0.051	0.024	0.074

Table 4. Optimal regression models of climate parameters on different scales of time.

Scale	Parameter	County	Model	R^2	Sig.	RSME
Year	T	AR	y = 0.041x - 63.444	0.636	0.000	0.37
		GY	y = 0.044x - 71.017	0.638	0.000	0.40
		JH	y = 0.030x - 42.317	0.453	0.000	0.40
		LW	y = 0.029x - 39.198	0.499	0.000	0.34
		YZ	y = 0.038x - 56.407	0.616	0.000	0.35
		YX	y = 0.040x - 62.525	0.663	0.000	0.34
Field period	S	LW	y = 3.944x - 7347.460	0.145	0.014	116.29
	T	AR	y = 0.046x - 69.662	0.541	0.000	0.51
		GY	y = 0.050x - 78.516	0.591	0.000	0.50
		JH	y = 0.038x - 53.371	0.448	0.000	0.51
		LW	y = 0.037x - 52.530	0.488	0.000	0.46
		YZ	y = 0.044x - 66.030	0.554	0.000	0.48
		YX	y = 0.044x - 65.278	0.542	0.000	0.49
Rooting stage	S	AR	y = 1.416x - 2736.073	0.284	0.000	27.27
		GY	y =2.124x - 5138.878	0.418	0.000	30.40
		JH	y =1.808x - 3520.986	0.308	0.000	32.87
		LW	y =2.617x - 5138.397	0.405	0.000	38.48
		YZ	y =1.195x - 2307.352	0.212	0.002	27.91
		YX	$y = 6.694 \times 10^{-121} \ln(x)^{36.995}$	0.331	0.000	0.32
	T	AR	y = 0.092x - 168.657	0.468	0.000	1.19
		GY	y = 0.096x - 176.709	0.444	0.000	1.30
		JH	y = 0.085x - 153.524	0.392	0.000	1.28
		LW	y = 0.069x - 122.566	0.302	0.000	1.27
		YZ	y = 0.076x - 135.684	0.357	0.000	1.23
		YX	y = 0.083x - 151.706	0.433	0.000	1.16
Flourishing stage	S	LW	y = 1.563x - 2974.449	0.109	0.035	54.17
	T	AR	y = 0.032x - 42.523	0.161	0.009	0.90
		GY	y = 0.042x - 61.200	0.251	0.001	0.87
		JH	y = 0.030x - 38.106	0.154	0.011	0.86
		LW	y = 0.032x - 41.236	0.185	0.005	0.81
		YZ	y = 0.039x - 55.293	0.265	0.001	0.79
		YX	y = 0.034x - 46.061	0.187	0.005	0.86
Maturing stage	S	AR	y = -1.697x + 3690.704	0.126	0.023	54.13
		YZ	y = -1.646x + 3560.366	0.137	0.017	50.19
		YX	y = -2.211x + 4724.763	0.245	0.001	47.11
	T	YZ	y = 0.021x - 15.534	0.144	0.014	0.63
	P	AR	y = 4.885x - 9456.659	0.131	0.020	152.91
		JH	y = 3.230x - 6191.652	0.117	0.029	107.83
		YZ	y = 3.526x - 6755.833	0.124	0.024	113.589

the optimal values. Precipitation was 789 mm in GY, 758 mm in JH and 794 mm in YX, within the optimal value, but P was 821 mm in AR, 827 mm in LW and 811 mm in YZ, higher than the optimal value. Long *et al.* (2003) reported that the optimal precipitation (P) for high quality tobacco of overseas regions is 89.8~138.3 mm in rooting stage, 124.6~163.8 mm in flourishing stage and 114.2~162.9 mm in maturing stage., In the six counties in Chenzhou City, P was 227~250 mm in rooting stage, 258~285 mm in flourishing stage and 269~314 mm in all counties in Chenzhou City indicating that all values were higher than those of the optimal values. The optimal sunshine hours in maturing stage was reported to be 280~300 hrs (Yang *et al.* 1987), S in this stage was 297 hrs in AR and YZ, 291 hrs in JH, 294 hrs in LW, and 290 hrs in YZ, within the optimal value, and S was 309 hrs in GY, higher than the optimal value.

Li *et al.* (2013) reported that the values of S from 1956 to 2005 in China showed a significant decreasing tendency (decreased by 0.012~0.023 hrs/y), T from 1951 to 2009 in China showed a significant increasing tendency (increased by 0.005˚C~0.008˚C y^{-1}) (The Second Time National Climate Change Assessment Report Authoring Group, 2011), and P from 1956 to 2015 in southern China showed in general increasing tendency (increased by 1.89 mm/y) (He *et al.* 2017). The same changing tendencies were also found in T and P in the present study, but comparatively, T and P increased by 0.029~0.044°C y and 0.572~4.095 mm/y, respectively. S also showed decreasing tendency in YZ and YX, decreased by 0.398~1.682 hrs/y, but showed increasing tendency in AR, GY, JH and LW, increased by 0.466~5.534 hrs/y. As for the changes of climate parameters during tobacco field-growth period, S generally showed a significant decreasing tendency (decreased by 1.08 hrs/y) and P showed an insignificant increasing tendency (increased by 1.5 mm y^{-1}) from 1961 to 2010 in Hunan (Zhang *et al.* 2012), while T showed a significant increasing tendency from 1981 to 2010 (increased by 0.040°C/y) (Chen *et al.* 2015a). The above changing tendencies were also found in T and P in the present study, T was significantly increased by 0.037~0.050°C/y and P was insignificantly increased by 1.109~2.774 mm/y. Sunshine hour also showed a decreasing tendency in AR, YZ and YX, decreased by 0.257~0.879 hrs/y, but showed an increasing tendency in GY, JH and LW, increased by 0.580~3.946 hrs/y. As for the changes of climate parameters in different tobacco growth stages, as Chen *et al*. (2015b) found that, from 1981 to 2010 in Guiyang County, both T and P increased in maturing stage, the same tendencies were found in T and P in the present study, which were increased by 0.015~0.022℃ y^{-1} and 2.810~4.893 mm/y, respectively.

Moreover, the increasing tendency of T (Pearson correlation coefficient > 0, Table 2,) is advantageous in rooting and flourishing stages but disadvantage in maturing stage for tobacco growth in the six counties because the optimal temperature for tobacco growth is 25~28℃. Because the optimal S for tobacco growth is 500~700 hrs in field-growth period, so the decreasing tendency of S in AR, YZ and YX (Pearson correlation coefficient < 0) is disadvantageous but the increasing tendency of S in GY, JH and LW (Pearson correlation coefficient > 0) is advantageous. The optimal P for tobacco growth was 700~800 mm in field-growth period, and the corresponding P was 821 mm for AR, 789 mm for GY, 827 mm for LW, 811 mm for YZ and 794 mm for YZ, so the increasing tendency of P in these counties (Pearson correlation coefficient > 0) is disadvantageous for tobacco growth. In maturing stage, the optimal S for tobacco growth is 280~300 hrs, S in maturing stage was 309 hrs in GY and 302 hrs in YX. So the decreasing tendency of S (Pearson correlation coefficient <0) is advantageous for tobacco growth. The optimal P for tobacco growth was 250~300 mm in maturing stage, and P was 314 mm in maturing stage in AR and LW, so the increasing tendency of P (Pearson correlation coefficient > 0) is disadvantageous for tobacco growth.

The present study also showed that different climate parameters changed differently in different regions and on different time scales in Chenzhou City, for examples, S changed irregularly in all six counties on the scales of year, field-growth period and growth stages except in maturing stage in LW ($P < 0.05$), but showed significant decreasing tendency in AR in maturing stage, YZ ($P < 0.05$) and YX ($P < 0.01$). T showed significant increasing tendency on the scales of year and field-growth period ($P<0.01$), but only showed significant increasing tendency in YZ in maturing stage ($p < 0.05$). Precipitation showed nonsignificant increasing tendency in all six counties on the scales of year and field-growth period, but showed significant increasing tendency in maturing field in AR, JH and YZ ($p < 0.05$) and showed nonsignificant increasing tendency in GY, LW and YX. The above results prove further that the model of climate parameter established in a particular region may not be applicable to other regions, it is necessary to setup the model with its own climate data in order to ensure the accuracy or reliability of the model.

It is apparent from the investigation that the main parameters in the six tobacco-planting counties in Chenzhou City changed differently on different scales of time, in which daily mean temperature in the six counties with tobacco-planting in Chenzhou City had significant positive linear correlation with year and daily cumulative precipitation changed irregularly on the scales of year, field-growth period of tobacco, and rooting and flourishing stages of tobacco, but they changed differently with year in maturing stage in different counties. Daily cumulative sunshine hour in the six counties had significant positive linear correlation with year on the scale of rooting stage, changed irregularly with year on the scale of year, and showed different change tendencies in different counties in flourishing and maturing stages. On the scale of field-growth period, daily mean temperature was lower than the optimal value in rooting and flourishing stages, but higher than the optimal value in maturing stage. Cumulative daily sunshine hour was mostly within the optimal values, cumulative daily precipitation in JH, GY and YX was within the optimal value, but higher than the optimal value in AR, LW and YZ. Cumulative daily precipitations in rooting, flourishing and maturing stages were all higher than the optimal values of overseas regions with high-quality tobacco. In maturing stage, S was within the optimal value in AR, JH, LW, YZ and YX, but higher than the optimal value in YZ. It is necessary to setup the model with its own climate data for a particular region in order to ensure the accuracy or reliability of the model. Further studies are needed to validate and improve the models established in this study, and attentions should be paid to other climate parameters to ensure the forecasting application of models more precise.

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