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KEY FACTORS AFFECTING COTTON YIELD IN SHIHEZI AREA OF XINJIANG PROVINCE, CHINA

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Abstract

The key factors affecting cotton yield per unit area was analyzed using the path analysis method. Results show the main meteorological factors affecting cotton yield per unit area are average temperature and evaporation; average temperature is the decision-making factor which exhibits a linear relationship with cotton yield per unit area while evaporation is the limiting factor. The main social input factors affecting cotton yield per unit area are agricultural electricity, irrigation amount, chemical fertilizers consumption and mechanical power, all of which show an exponential relationship with cotton yield per unit area. Moreover, as the average temperature increases by 1ºC, cotton per unit area yield will increase by 1 kg/ha, and the inputs of irrigation amount, mechanical power, agricultural electricity, chemical fertilizers consumption will increase by 0.76 m^3/kg, 1.42 W/kg, 1.35 Kwh/kg and 0.52 kg/kg, respectively. Comprehensive analysis shows that the direct effect of meteorological factors on cotton yield per unit area is 1.1931 and that of social input factors is 0.8070.

Introduction

Cotton is the main crop in Shihezi reclamation area, the average proportion of sowing was 47.18% during the period between 1980 and 2009 and reached its highest point to 89.63% in 2007. During this period, crop yields per unit area (CYPUA, hereafter) has been increased from the initial yield of 150 to 2322 kg/ha in 2009 due to updated cotton cultivation technology (Shihezi Statistic Bureau 2010).Meanwhile, Shihezi area has become a feasible-cotton zone from a secondary-feasible-cotton zone, because of climate change and production inputs (Xu *et al*. 1995, Zhu 2008, Pan *et al*. 2000). Previous studies have shown that crop yields were mainly affected by the improvement of socio-production level and climate changes (Climate Change and Crop Yield Writing Group1992, Yao and Zhang 2008). So the factors affecting crop yield can be divided into two parts: one is social investment and productivity, and the other is climate change.

Path analysis was proposed by Wright and formed on the basis of path coefficient (Wright 1921). Path analysis can determine either the relationship between two variables or the importance of reason to results. It divides correlation coefficients into direct and indirect impacts and reveals the relative importance of various factors to results with the feature of intuitive and accurate (Yuan *et al*. 2001). To date, the path analysis method has been widely used in analysis of crop yields and its impact factors (Zheng *et al*. 2009, Shi 2009, Cai *et al*. 2008). The main objective of this study was to investigate the key factors influencing CYPUA in the Shihezi area using path analysis to provide insight into future production.

Materials and Methods

Shihezi reclamation area (43º27'N, 84º58'E to 45º20'N, 86º30'E) is located at the south margin of Gurbantunggut desert in Xinjiang province, China. The average altitude of this site is 300-500 m. It belongs to a typical temperate continental climate, with a long-cold winter and a short-hot

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summer. The average temperature is 7.2ºC; sunshine hour is 2318 - 2732 hrs; the frost-free period is 147 - 191 days; the annual precipitation is 110 - 200 mm; and the annual potential evaporation is 1000 - 1500 mm. The area of Shihezi is about 7529 km^2, with arable area about 22.31 × 104 hm^2, which is also one of the main cotton producing areas in Xinjiang. Management level in Shihezi reclamation area is a strong representation of cotton plantation in Xinjiang. The water resources of Shihezi area mainly come from Manas river, which originate from Tianshan Mountains and end in Manas Lake; the annual flow is 12.74 × 108 m^3. The annual flow varies greatly due to seasonal change. Snow in Tianshan Mountains melts strongly in summer (June to August), and supplies 60 - 70% runoff in the whole year.

Meteorological factors include average temperature (ºC), precipitation (mm), sunshine hours (hrs) and daily mean wind velocity (m/s); social input factors include irrigation amount (m^3/ha), chemical fertilizers consumption (kg/ha), pesticide amount (kg/ha), mechanical power (W/ha), agricultural electricity (Kwh/ha) and number of employee. In Shihezi reclamation area, cotton is sown in April, and harvests in September, therefore, the meteorological elements mainly choose the materials of April to September. The historical period of these materials is from 1959 to 2008, coming from Shihezi Socio-economic Statistics Yearbook (1996 - 2009).

Correlation analysis was used to pre-screen the factors. Then the pre-screened factors were further analyzed by the method of path analysis (Wright 1921, Mao *et al.* 2009). The results are conducted by using the SPSS16.0 software and Matlab 7.0.1 software package.

Results and Discussion

Pearson correlation coefficients between CYPUA and meteorological factors including average temperature (a_1), precipitation (a_2), sunshine hours (a_3), evaporation (a_4), and daily mean wind velocity (a_5) are shown in Table 1. Average temperature, sunshine hours and evaporation had significant correlations ($p < 0.01$) with CYPUA. However, precipitation and daily mean wind velocity had no significant correlations with CYPUA. The results of path analysis are shown in Table 2.

Table 1. Correlation analysis of meteorological factors and CYPUA.

	Average temperature	Precipitation	Shine hours	Evaporation	Daily mean wind velocity	CYPUA
a_1	1	–0.2651	0.5455**	0.1396	–0.2450	0.5748**
a_2		1	–0.1159	–0.4821	–0.1221	0.1880
a_3			1	–0.0749	–0.2641	0.4587**
a_4				1	–0.0519	–0.4966**
a_5					1	–0.2175

**Suggest the correlation is significant at $p < 0.01$, N = 50.

The direct impacts of average temperature and evaporation on crop production were significant, while indirect impacts of sunshine hours and wind velocity were relatively strong. In meteorology, sunshine hours and wind velocity all play important roles. The longer the sunshine hours, the higher the average temperature; and the stronger wind was one of reasons to reduce the average temperature. Therefore, sunshine hours play a positive role in average temperature and it reached 0.3371; while wind velocity play a negative role in average temperature and it reached 0.1509. Thus, sunshine hours and wind velocity can affect CYPUA, through whose effect on average temperature. Similarly, although the precipitation is small, it is also shown some influence on CYPUA with the conversion to warm-humid climate. This influence was achieved mainly through its negative effect on average temperature and positive effect on evaporation.

According to the results, the order of each decision coefficients is: $R^2_{(1)} > R^2_{(4)} > R^2_{(2)} > R^2_{(3)} > R^2_{(5)}$, i.e., average temperature > evaporation > precipitation > sunshine hours > daily mean wind velocity. The decision-making coefficients of average temperature and evaporation has reached 0.3285, 0.2820, respectively much higher than other factors.

Table 2. Path analysis on effects of meteorological factors on CYPUA.

Variable	Direct effect	Indirect effect	Path analysis coefficient matrix					Decision-making coefficient (R^2_i)	F
			r_1y	r_2y	r_3y	r_4y	r_5y		
a_1	0.6180	–0.0432		–0.0254	0.0417	–0.0746	0.0151	0.3285	34.1921
a_2	0.0957	0.0924	–0.1640		–0.0089	0.2576	0.0077	0.0582	0.8739
a_3	0.0764	0.3823	0.3371	–0.0111		0.0400	0.0163	0.0144	0.5363
a_4	–0.5342	0.0376	0.0863	–0.0461	–0.0057		0.0031	0.2820	28.9110
a_5	–0.0618	–0.1557	–0.1509	–0.0119	–0.0201	0.0272		0.0038	0.4592

(1) Correlation coefficient $R^2 = 0.6869$, D = 0.1295; (2) F is the numerical test at 0.05 level.

Based on the above analysis, average temperature and evaporation were used to estimate CYPUA using regression analysis. The regression equation was as follows:

$$Y = –4398.41 + 451.9892*a_1 – 2.2836*a_4 \quad (1)$$

where Y was CYPUA (kg/ha); a_1, a_4 were the average temp. (ºC) and evaporation (mm).

$F = 47.5922$, $p < 0.001$, correlation coefficients : $R^2 = 0.6694$.

Results show that CYPUA was closely allied to average temperature and evaporation. However, the direct impacts of evaporation on CYPUA are a negative number, illustrating that evaporation is the limiting factor affecting CYPUA. Generally, greater evaporation will result in greater degree of dry-airing, which has more negative effect on crop growth (Agro-meteorological of Beijing Agricultural University compile 1982). Because Shihezi is located at the edge of desert, its potential evaporation greatly exceeds the evaporation necessary for crop growth. Therefore, evaporation and CYPUA are negatively related.

The main factors affecting evaporation are temperature and wind velocity. The acting coefficient of average temperature with evaporation is 0.0863, implying that evaporation is affected by temperature and there is an interaction between them. In order to illustrate better the effects of climatic change and social input on CYPUA, it is necessary to extract the most important factor affecting CYPUA. The relationship between CYPUA and average temperature is shown in Fig. 1.

According to the regression equation cited above, it could be seen that the linear relationship between them were achieved. Cotton is the thermophilic crop, climatic change has an important influence on its growth. Therefore, the main factor affecting cotton plantation in Shihezi area was average temperature, which is consistent with the previous reports (Tang *et al.* 2010, Lv and Ma 1997).

Fig.1 showed that overall CYPUA increased with the average temperature. However, the correlation between them was relatively weak ($R^2 = 0.3302$), suggesting that average temperature is only one of the factors affecting CYPUA. Therefore, it is necessary to further analyze the effect of social input on CYPUA.

According to social production conditions of Shihezi reclamation area, the social input factors affecting cotton production were irrigation amount (b_1), mechanical power (b_2), agricultural electricity (b_3), pesticide amount (b_4), chemical fertilizers consumption (b_5) and number of employed (b_6). The Pearson correlation coefficients between social input factors and CYPUA were shown in Table 3. In general, irrigation amount (b_1), mechanical power (b_2), agricultural electricity (b_3), and chemical fertilizers consumption (b_5) exhibit a positive correlation with CYPUA and the correlation coefficient was significant at the 0.01 level. Pesticide amount (b_4) and the number of employed (b_6) exhibited negative correlation with CYPUA. The correlation between pesticide amount and CYPUA was insignificant while significant correlation existed between the number of employee and CYPUA.

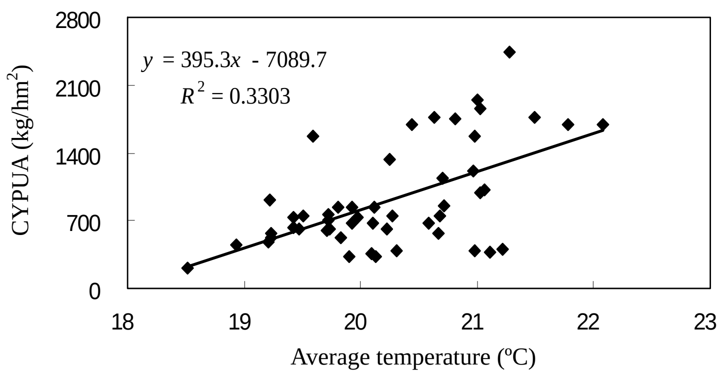

Fig. 1. Relationship between average temperature and CYPUA

Regression equation was as follows:

$Y = -7093.87 + 395.4864*a_1$ (2)

Where Y was CYPUA (kg/ha), a_1, the average temperature

$F = 23.6592$, $p = 0.0001$, $R^2 = 0.3302$

Table 3. Correlation analysis of social input factors and cotton per unit area yield.

	b_1	b_2	b_3	b_4	b_5	b_6	y
b_1	1.0000	0.6429**	0.5610**	–0.2175	0.7032**	–0.3278*	0.7140**
b_2		1.0000	0.9611**	–0.2210	0.9573**	–0.4390**	0.8991**
b_3			1.0000	–0.1005	0.9024**	–0.5455**	0.9138**
b_4				1.0000	–0.2107	0.1628	–0.1107
b_5					1.0000	–0.4421	0.9094**
b_6						1.0000	–0.5522**

** suggest the correlation is significant at $p < 0.01$. * Suggest the correlation is significant at $p < 0.05$.

Path analysis was used to analyze the impact of social input factors on CYPUA (Table 4). The decision-making coefficients of various factors were calculated, the order was : $R^2_{(3)} > R^2_{(1)} > R^2_{(5)} > R^2_{(6)} > R^2_{(4)} > R^2_{(2)}$, i.e. agricultural electricity (b_3) > irrigation amount(b_1) > chemical fertilizers consumption (b_5) > number of employed (b_6) > pesticide amount (b_4) > mechanical power (b_2).

According to F-test value and decision-making coefficient, the main decision-making factors affecting CYPUA were irrigation amount (b_1), agricultural electricity (b_3) and chemical fertilizers consumption (b_5). Shihezi is a typical irrigated agriculture district, where agriculture irrigation requires a large number of electrical equipment. Meanwhile, the demand for irrigation water also controls the increase of agricultural electricity. In addition, fertilizer is an important material input of agricultural production which exhibits a high correlation with the increase of CYPUA. Therefore, the conditions of water and fertilizer have an important influence on CYPUA.

Table 4. Path analysis on effects of social input factors on cotton per unit area yield.

Varia-bles	Direct effect	Indirect effect	Path analysis coefficient matrix						Decision-making coefficient (R^2_i)	F
			r_1y	r_2y	r_3y	r_4y	r_5y	r_6y		
b_1	0.2391	0.4749		–0.3784	0.4875	–0.0025	0.3560	0.0124	0.2843	13.4421
b_2	–0.5887	1.4877	0.1537		0.8351	–0.0025	0.4846	0.0168	–1.2240	3.5053
b_3	0.8689	0.0449	0.1342	–0.5658		–0.0012	0.4568	0.0209	1.5831	13.0874
b_4	0.0114	–0.1221	–0.0520	0.1301	–0.0874		–0.1066	–0.0062	–0.0025	0.0438
b_5	0.5062	0.4032	0.1682	–0.5636	0.7841	–0.0024		0.0169	0.2734	8.5089
b_6	–0.0383	–0.5139	–0.0772	0.2575	–0.4730	0.0018	–0.2229		0.0015	0.3537

(1) Correlation coefficient R^2 = 0.9129, D = 0.0001. (2) F is the numerical test at 0.05 level.

F-test value and decision-making coefficient indicate that mechanical power (b_2) and CYPUA were negatively related, and that of mechanical power was the limiting factor affecting CYPUA. For a long time, the number of people engaged in agricultural production varied greatly in Shihezi area, change of the number of planting practitioners as shown in Fig. 2.

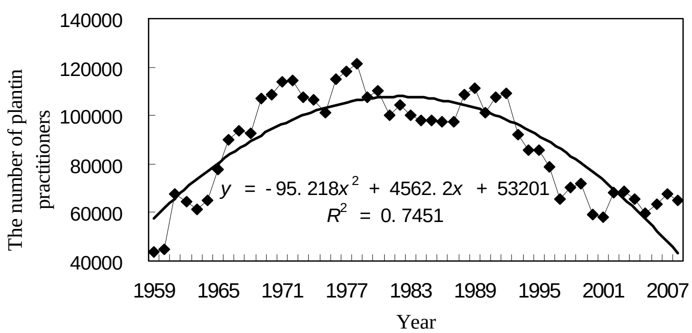

Fig. 2. Change of the number of planting practitioners in Shihezi reclamation area.

The population of planting practitioners increased from 1959 to 1978. Thereafter, a downward trend was observed. Therefore, the agricultural production in Shihezi mainly depends on machine rather than the number of employee, which supported the results of Table 4. Automated manufacturing requires power input, so the acting coefficient of agricultural electricity with mechanical power was 0.8351.

The relationships between irrigation water, mechanical power, agricultural electricity, chemical fertilizers consumption and CYPUA were analyzed (Figs 3-6), all of which showed an optimal exponential relationship with CYPUA. Results showed that as a typical irrigated agriculture district, with the increasing of irrigation amount, mechanical power and chemical fertilizers consumption, CYPUA has also gradually increased in recent 50 years.

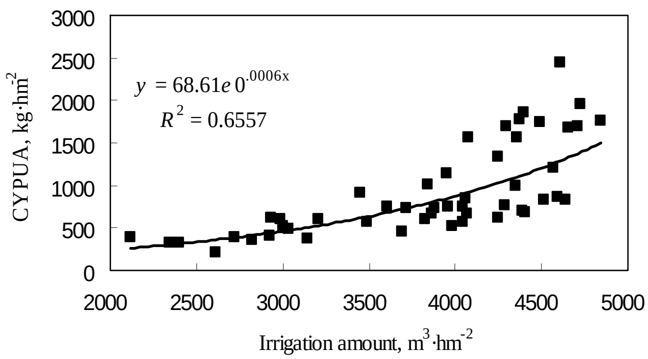

Fig. 3. Relationship between irrigation amount and yield of cotton per unit area.

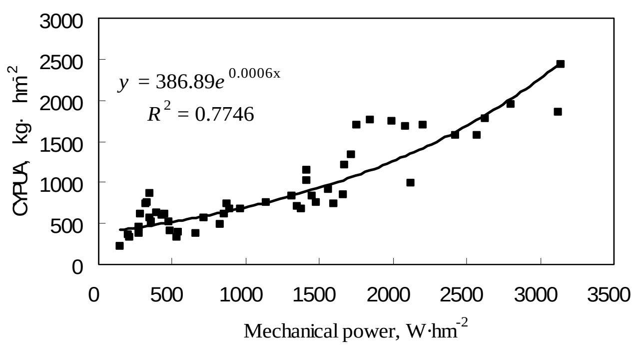

Fig. 4. Relationship between mechanical power and yield of cotton per unit area.

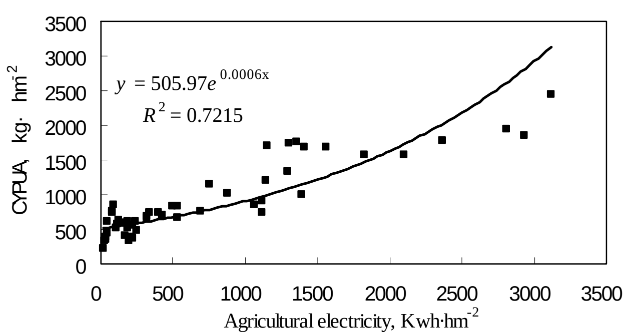

Fig. 5. Relationship between agricultural electricity and yield of cotton per unit area.

Although each social input factor exhibited an exponential relationship with crop yields, the exponential coefficients were small. According to Taylor expansion, this exponential relationship can be approximately seen as a linear relationship (Mathematics Department of East China Normal University Compile 1991). Removing the factors of pesticide amount (b_4) and the number of employee (b_6), the regression equation including CYPUA and four factors were obtained:

$$Y = -81.5579 + 0.1819*b_1 - 0.4323*b_2 + 0.6213*b_3 + 0.9311*b_4 \quad (3)$$

where, Y was CYPUA (kg/ha); b_1, b_2, b_3, b_4 were the irrigation amount (m^3/ha), mechanical power (W/ha), agricultural electricity (kg/ha) and pesticide amount, respectively.

F = 121.2154, p = 0.0001, $R^2 = 0.9151$.

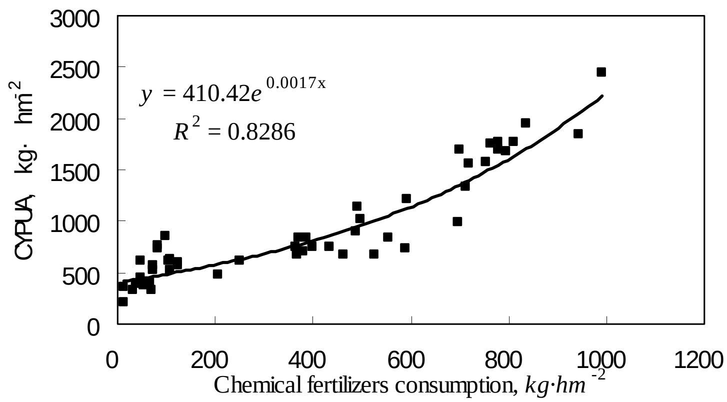

Fig. 6. Relationship between chemical fertilizers consumption and yield of cotton per unit area.

CYPUA is the goal of cotton plantation, meteorological factors are unchangeable facts. To pursue the increase of cotton yields, we could constantly increasing social inputs according to the growth characteristics of cotton, in order to overcome the unfavorable influence, which is under the condition of weather change. With climate changing, the trend in input and output will be the main concern for cotton production in the future. Therefore, if the yield of cotton was obtained, the influence of climatic change on social input-output could be analyzed according to the relationship between meteorological factors and input-output.

The aim of increasing input in agricultural production is to pursue the maximum benefit. Through analysis on the effects of average temperature on each social input factors and social output, these multiple factors influence was consider as a normal tendency and analyzed by regression method (Table 5).

According to the equation cited above, the optimal linear relationships between average temperature and irrigation amount, mechanical power, agricultural electricity, chemical fertilizers consumption were achieved. As the average temperature increases 1ºC, the maximum yields of cotton increases by 395.30 kg/ha and the inputs of irrigation amount, mechanical power, agricultural electricity, chemical fertilizers consumption will increase by 300.03 m^3/ha, 559.37 W/ha, 533.5 Kwh/ha and 204.6 kg/ha, respectively ; on the other hand, as the average temperature increase 1ºC, CYPUA will increase by 1 kg/ha and the inputs of irrigation amount, mechanical power, agricultural electricity, chemical fertilizers consumption will increase by 0.76 m^3/ kg, 1.42 W/kg, 1.35 Kwh/kg and 0.52 kg/kg at the same time, respectively. According to the role of input factors, we understand that this increase is mainly to overcome the negative elements of meteorological conditions and to meet the material needs necessary for increasing production.

By analyzing the main factors of meteorological and social input, the relationship between CYPUA and main effecting factors was established, based on which one can fit the value of theoretical yield (binomial fitting yield) under the effects of meteorological and social input. This yield value is the direct impacts of meteorological and social input factors, based on which one can get the contribution degree of meteorological factors and social input factors to CYPUA.

Table 5. Relationship between average temperature and input factors.

y	Regression equation	R^2	F	P	As the temperature change 1, the maximum increase amount of input and output	As the temperature change 1, the relative output increase amount of input factors
b_1	y = 300.03x - 2248	0.1043*	5.5800	0.0223	300.03	0.76
b_2	y = 559.37x - 10129	0.2631**	17.1073	0.0001	559.37	1.42
b_3	y = 533.5x - 10055	0.2530**	16.2222	0.0002	533.50	1.35
b_5	y = 204.6x - 3763.5	0.2749**	18.1741	0.0001	204.60	0.52
CYPUA	y = 395.3x - 7089.7	0.3303**	23.6592	0.0001	395.30	1

(1) In regression equation where x is the average temperature. (2) **Suggest the correlation is significant at $p < 0.01$ level. *Suggest the correlation is significant at $p < 0.05$ level, N = 50.

Regression of the relationship between fitting yields of social input factors and meteorological factors and real yields were achieved, the equation obtained was as follows:

$$Y = -73.0676 + 0.8436X_1 + 0.2360X_2 \quad (4)$$

where Y is CYPUA (kg/ha); X_1, X_2 were the fitting yield of social input factors (kg/ha) and fitting yield of meteorological factors (kg/ha), respectively.

$F = 312.1621$, $p < 0.001$, $R^2 = 0.9300$

The equation cited above illustrates that X_1 and X_2 can better reflect the real yield (Table 6).

Table 6. Effects of social input factors and meteorological factors on yield of cotton per unit area.

Acting factor	Direct effect	Indirect effect	Path analysis coefficient matrix	
			r_1y	r_2y
x_1	0.8070	0.1496		0.1496
x_2	0.1931	0.6251	0.6251	

The remaining path coefficient was 0.2646, which means the effects of meteorological factors and social input factors on CYPUA were strong. In Shiheizi reclamation area, the direct coefficients of social input factors and meteorological factors were 0.8070 and 0.1931, respectively; which was to say, social input factors played a dominant role in cotton production. Combined with the conclusion of 3.4, that social inputs not only need to overcome the negative effects brought by the increasing temperature, the purpose of which is to make the increasing temperature propitious to cotton yields, but also need to meet the material needs necessary for the increase of cotton yields. To pursue the maximum yields, the process of cotton production as well as the growth of natural vegetation follows the same principles: make full use of the light (temperature), that is to say, with the continuous social inputs (increase water and fertilizer) to improve the use of temperature, the maximum output and increase the utilization of temperature can also be achieved (Peter 2008).

Various factors are responsible for the cotton production; the major factors of production are natural factors and human factors. Of the above factors, meteorological is the main condition of natural factors, it also can be meteorological indicators to quantify the reaction. Cotton is thermophilic, the temperature directly affects the growth and yield components of cotton.

This finding suggested that a moderate increase in average temperature was beneficial to the increase of cotton yield, this is consistent with previous research results (Tang *et al.* 2010, Lv *et al.* 1997). According to the principles of agricultural meteorology, the greater the air dryness and evaporation, the less the growth of crops (Duan *et al*. 2002). Shihezi is located in the edge of the desert, evaporation is far more than the evaporation of water which is necessary for crop growth, thus evaporation is a limiting factor affecting cotton yield.

Analysis of the effect of human factors on cotton yield and according to the local existing data, the irrigation amount, mechanical power, agricultural power consumption, chemical fertilizers consumption and other indicators were used. Agricultural production in this region mainly depends on the mechanical, mechanization requires the operator to master certain skills and professional knowledge, thus the cultural level of growers also has an impact on cotton yields (Lokhande and Reddy 2015). Effect of the irrigation amount and fertilizers consumption on the yield is obvious (Howard *et al*. 2001, Zakaria 2016).

In a particular region, years of climate conditions are relatively stable, agricultural production increasingly dependent on investment in human factors. Results confirm that in Shihezi, the amount of irrigation water, mechanical power, agricultural power consumption and chemical fertilizers consumption directly affects crop yields (Zakaria 2017). In comparison, the climate effect is relatively weak. This is similar to the development trend of modern agricultural production, which is increasingly dependent on human input (John *et al*. 2017).

By analyzing the relationship between meteorological factors, social inputs and CYPUA in Shihezi area from 1959 to 2008, following conclusions were made:

(1) In accordance with the order of decision-making coefficient, the effects of various meteorological factors on CYPUA followed such sequence: average temperature > evaporation > precipitation > sunshine hours > daily mean wind velocity. According to the relationship between meteorological factors and CYPUA, conclusion made: the key factor affecting CYPUA was average temperature and the limiting factor was evaporation.

(2) The decision-making coefficient also suggested that the effects of various social input factors on CYPUA followed this sequence: agricultural electricity > irrigation amount> chemical fertilizers consumption > number of employed > pesticide amount > mechanical power. Analysis of the relationship between social input and CYPUA, results revealed that irrigation amount, mechanical power, agricultural electricity and chemical fertilizers consumption were closely correlated with CYPUA and that of pesticide amount and number of employed had no significant influence. The decision-making factors affecting the CYPUA were irrigation amount, agricultural electricity and chemical fertilizers consumption, whereas the limiting factor was mechanical power.

(3) As the average temperature increase by 1ºC , CYPUA will increase by 1 kg/ha, and the inputs of irrigation amount, mechanical power, agricultural electricity, chemical fertilizers consumption would increase by 0.76 m^3/ kg, 1.42 W/kg, 1.35 Kwh/kg and 0.52 kg/kg at the same time.

(4) The direct impacts of meteorological factors and social input factors on CYPUA were 0.8070 and 1.1913, and the effect of social input factors from exceeds from the meteorological factors.

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