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Climate Change and its Impacts on the Winter Wheat Yield in Wugong Region of Shaanxi Province

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Abstract: Understanding the impacts of climate change on the Winter wheat yield in Wugong region is important for effectively making relevant countermeasures and policy. Based on the monthly weather data and Winter wheat yield data in Wugong station from 1935-2010, the Mann-Kendall Method, Rescaled Range Analysis Method (R/S), Straight Line Slipping Average Simulating Method and Path Analysis Method were adopted to study the changing tendency of the main meteorological factors, the aridity-humidity as well as the impacts of climate change on the winter wheat yield in Wugong region. The results have shown that the minimum temperature had an increasing trend, the wind speed, hours of sunshine and ET_0 were all gradually decreasing, they have come to a remarkable level; SPI was dropped, the climate trended to be drought gradually. Hurst indexes of ET_0 and SPI (annual value and winter wheat growth period) were all >0.5 which will appear to be the persistent trend in the future. The minimum temperature increasing trend had the most powerful comprehensive determined ability on winter wheat yield; the maximum temperature was the major limited weather factor of the Winter wheat yield increasing. However, the negative impact of climate change on the winter wheat production in Wugong region can be mitigated to some extent by some technological innovations.

Key words: Wugong region, climate change, SPI, Winter wheat, yield

INTRODUCTION

With the increasing of the greenhouse effect, the global warming, climate change and its effects on the agriculture production have drawn more and more public's attention (Rosenzweig *et al*., 2000). National Assessment Report of Climate Change shows that the average temperature of China maybe rise 1.3~2.1°C in 2020, the annual average rainfall maybe increase 2~3% (Ding, 2006). Climate Warming probably causes precipitation increasing in some regions of China but the final decreasing of the soil available water caused by the increasing of moisture evaporation capacity results in the reduction of the crop yield (Wang *et al*., 2004). Recent years, climate change in the North of China has been more obvious than it in other regions (Lu *et al*., 2009), the ecological environment has been more fragile and the impact of climate change on grain production also has been more serious than it in other regions (Hou, 2008). According to the simulated results of the climate scenarios, the great impact of intense climate change on the food security in China will be more inescapable in the coming 50~100 years (Ding, 2006; Xu, 2005).

At present, domestic and overseas scientists have chiefly adopted imitation model and control test to estimate the impacts of future climate change on crop yield (Brown and Rosenberg, 1997; Reilly *et al*., 2003; Lin *et al*., 2005; Luo *et al*., 2005; Song *et al*., 2006) but the historical analysis was relatively less, especially, the historical analysis of longer time series (Lobell and Asner, 2003; Carter and Zhang, 1998; Peng *et al*., 2004; Naylor *et al*., 2002). In China, the Winter wheat sowing acreage has accounted for >85% of the wheat's total, its gross production has approximately occupied 90% of the wheat's total (Zhang *et al*., 2000). Wugong region is one of the main production districts of Winter wheat in China in recent decades, climate changed remarkably which has a serious impact on Winter wheat production. Under this background, the key point of this study is how to quantitatively estimate the influence degree of climate change on Winter wheat yield under the climate change scenarios. In order to provide district demonstrative basis for estimating impacts of global climate change on agriculture production and provide scientific basis and decision-making support for further researching the negative influence of climate change on agriculture, this

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study has taken Wugong region of Shaanxi Guanzhong plain as an example which has analyzed the trend of climate change and its impacts on main grain crop Winter wheat yield during the recent 76 years.

MATERIALS AND METHODS

The general situation of study region: Wugong region has a continental monsoon climate which is located in the Weihe river basin between Qinling Mountain and loess plateau, its average temperature was 13.3°C in the recent 76 years and its average precipitation was 607.7 mm, rich sunshine, flat and fertile land. Wugong region is one of main granaries in the Guanzhong plain, whose main crops are Winter wheat and Winter wheat. The terrain is South sinking and North rising and the elevation is 411~603 m. The geographical position is N34.2°~34.43°, E108°~108.33°.

Materials: The monthly weather data (monthly average temperature, monthly average maximum temperature, monthly average minimum temperature, hours of sunshine, monthly average wind speed, monthly mean relative humidity and precipitation (separately indicated by x_1, x_2, x_3, x_4, x_5, x_6, x_7) in 1935~2010 origined from the weather station in Wugong County (N34.15°, E108.13°, 447.8 m altitude), the Winter wheat yield data in 1935~2010 came from the Wugong County Annals and the annual report of Bao Jixia Irrigation district of drawing Weihe river; Reference crop evapotranspiration was obtained by the Penman-Monteith equation which recommended by FAO in 1990 to estimate the reference crop evapotranspiration (Allen *et al*., 1994; Clarke, 1998).

Analysis method: Mann-Kendall Method was adopted to test the trend of weather data (Yue *et al*., 2002; Liu and Zheng, 2004; Yu *et al*., 2002), Rescaled Range Analysis Method (R/S) was adopted to analyze the turn point change of hydrology and climate (Pallikari and Boller, 1999), Straight Line Moving Average Simulation Method was adopted to simulate the tendency of weather and food production (Wang *et al*., 1990), Path Analysis Method was adopted to analyze the contribution ratio of main meteorological factors change on food yield (Wright, 1934; Yuan and Yun, 2007; Bhatt, 1973). Path Analysis Method was a multivariate statistical analysis technology which was brought up by quantity geneticists Sewell Wright in 1921 and continuously improved by genetic breeding scholars which was adopted to study the interrelationship between variables and dependent variables and the role of independent variable to the dependent variable. Based on Path Analysis Method, researchers can obtain direct effects and indirect effects of independent variable to the dependent variable and directly reveal the ralative importance of each factor to the results through the decision-making coefficient which are intuitionistic, accurate, etc.

The trend analysis of climate change

The change characteristic of main weather factors: The Mann-Kendall Method was adopted to test the long-term change tendency of annual weather factors and weather factors in July (the month of maximum temperature), January (the month of minimum temperature), rainy season (from July to September), dry season (from November to the next March) and Winter wheat growth period (from Mid-October to 1 June). The results showed in Table 1.

Table 1 can show that among annual value series of weather factors, the average temperature, minimum temperature and relative humidity were trend to increase; the maximum temperature, wind speed, hours of sunshine and precipitation had a downtrend; among which the increase of minimum temperature, the decrease of wind speed and hours of sunshine all indicated an extremely significant level and whose tendency rate separately reached to be 0.204°C/10a, -0.077 m sec^{-1}/10a, 61.984 h/10a. Except the relative humidity change trend was opposite to annual values series, during the Winter wheat growth period, other indexes were the same to annual values series; the tendency rate of minimum temperature, wind speed and hours of sunshine separately reached to be 0.248°C/10a, -0.085 m sec^{-1}/10a

Table 1: Weather factors Mann-Kendall trend test results in Wu Gong station

Time interval	x_1/°C	x_2/°C	x_3/°C	x_4/h	x_5/(m sec^{-1})	x_6	x_7/mm	ET_0/mm	SPI
January	1.65*	0.64	5.01**	-3.53**	-4.22**	-1.85**	0.12	-1.18	0.12
July	-0.46	-2.28*	1.74	-4.57**	-1.46	0.61	-1.74	-2.61**	-1.74
Rainy season	-0.99	-2.88**	3.42**	-4.13**	-2.69**	2.24*	-1.55	-3.43**	-1.55
Dry season	1.48	-0.13	5.63**	-4.29**	-4.68**	-1.37	-0.74	-2.22*	-0.74
Annual value series	0.07	-1.89	6.10**	-4.81**	-3.54**	1.47	-1.53	-3.66**	-1.53
Winter wheat growth period	1.27	-0.70	6.13**	-3.92**	-4.22**	-0.53	-0.64	-1.59	-0.64

x_j(j = 1-7) separately stand for monthly average temperature, monthly average maximum temperature, monthly average minimum temperature, hours of sunshine, monthly average wind speed, monthly mean relative humidity and precipitation; * is significant at the 5% level; ** is extremely significant at the 1% level. Positive stands for increasing tendency, negative stands for decreasing tendency

Table 2: Main weather factors Mann-Kendall trend test results in the Winter wheat growth period

Months	10	11	12	1	2	3	4	5
x_3/°C	2.90**	2.38*	3.06**	5.01**	3.46**	3.38**	2.86**	3.59**
x_4/h	-3.02**	-2.70**	-3.71**	-3.53**	-2.21*	-1.32	0.40	-1.04
x_5/m sec^{-1}	-3.39**	-4.12**	-3.94**	-4.22**	-4.19**	-3.86**	-3.75**	-1.68

x_j (j = 3-5) separately stand for monthly average minimum temperature, hours of sunshine, monthly average wind speed; * is significant at the 5% level; ** is extremely significant at the 1% level; positive stands for increasing tendency, negative stands for decreasing tendency

and -28.463 h/10a. In order to search out the contributions of the monthly minimum temperature, hours of sunshine and wind speed during the Winter wheat growth period, researchers have particularly analyzed them (Table 2). It turned out that the increasing tendency of minimum temperature has shown a significant or an extremely significant level during the Winter wheat growth period and also the decreasing tendency of hours of sunshine has shown a significant or an extremely significant level during January, February, October, November and December and also the decreasing tendency of wind speed has shown an extremely significant level during January, February, March, April, October, November and December. So, researchers can draw a conclusion that the months which made a supreme contribution to the increasing tendency of minimum temperature, the decreasing of hours of sunshine and wind speed during Winter wheat growth period were in January, February, March, April, May, October, November and December; January, February, October, November and December; January, February, March, April, October, November and December.

Reference crop Evapotranspiration (ET_0): Mann-Kendall Method was adopted to analyze the long-term change tendency of annual ET_0 and ET_0 in 5 typical time when they were in July (ET_0 was maximum), January (ET_0 was minimum), rainy season, dry season and Winter wheat growth period (Table 1). The results show that in the recent 76 years, annual ET_0, ET_0 in July and rainy season were all trend to decrease which have reached an extremely significant level, their change rate was separately -11.35, -2.81 and -6.39 mm/10a; ET_0 in dry season dropped which have come to a significant level, its change rate was -4.97 mm/10a. Referring to the existing research (Cao *et al*., 2007), they were the coaction's results of the extremely significant decreasing wind speed and hours of sunshine, the drop of maximum temperature, precipitation, etc. The long-term change tendency of ET_0 in winter wheat growth period and annual ET_0 are showed in Fig. 1. ET_0 in winter wheat growth period and annual ET_0 all have shown a fluctuant downtrend whose long-term change curves all had 3 crests and 2 troughs. Their change tendencies were similar but change ranges were different.

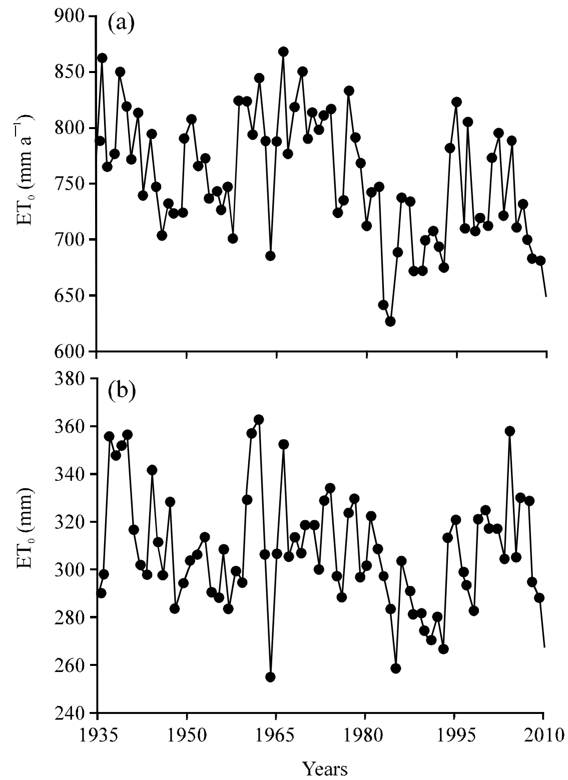

Fig. 1: ET_0 change trend in Wu gong station; a) annual ET_0 change trend; b) ET_0 change trend in Winter wheat growth period

Aridity-humidity change: Standardized Precipitation Index (SPI) is used to measure the aridity-humidity condition of special time scale in the precipitation-recorded region whose counting principle, method and drought classification origin from the literature (Guttman, 1999; Wu *et al*., 2007). SPI and Mann-Kendall Method were adopted to analyze the aridity-humidity state and aridity-humidity change tendency in Wugong region (Fig. 2 and Table 1). In Fig. 2a, researchers can get that since, 1935a, Wugong region was excessively threatened by drought in 1977a, severe drought threatened this area in 1986a, 1995a, 1997a, 2001a and the drought-affected years take up 56.5% of the drought-affected years' total since 1980 which illustrate that the meteorological drought degree became more and more serious, its frequency occurred more and more often in the recent 30 years. From Fig. 2b, researchers can know that since, 1935a in Winter wheat growth period, Wugong region was excessively hit by the drought in 1941a, severe drought hit this area in 1939a, 1951a, 1979a, 1986a and the drought-affected years take up 34.8% of the drought-affected years' total since 1980 which show that the meteorological drought degree became weaker, its

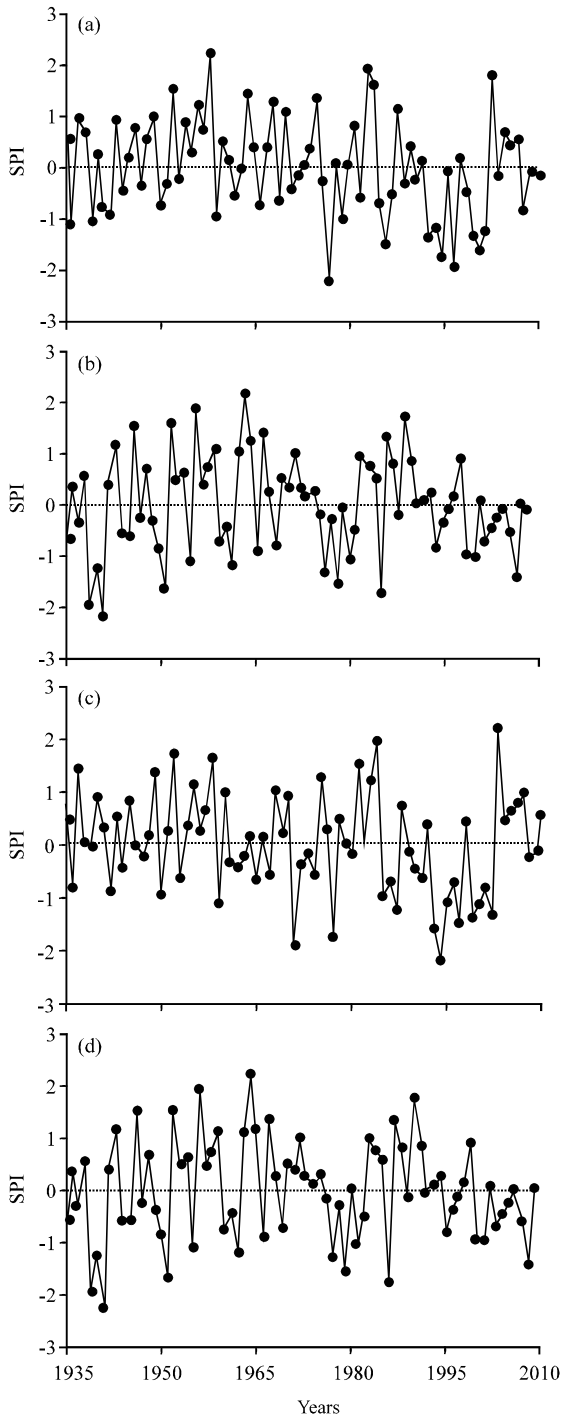

Fig. 2: SPI change trend in Wu gong station; a) annual SPI change trend; b) SPI change trend in Winter wheat growth period; c) SPI change trend in rainy season; d) SPI change trend in dry season

occurrence frequency dropped in the recent 30 years but SPI was trend to decrease significantly. Looking at the long-term change tendency, can be found out the annual SPI, SPI (in Winter wheat growth period, rainy season, dry season and July) were trend to decrease in Wugong region and climate was developing into aridity; SPI (in January) were trend to increase and climate was developing into humidification. But its decreasing trend or increasing trend was not so significant in each stage.

Table 3: Hurst index and change point of weather indexes

Time interval	Hurst index of ET_0	Hurst index of SPI	ET_0 variation year	SPI variation year
Annual average	0.880	0.660	1984	1987
Winter wheat growth period	0.623	0.559	1982	1998

The analysis of the weather indexes variation points: Penman-Monteith formula was adopted to get ET_0 which includes maximum temperature, minimum temperature, average temperature, wind speed, relative humidity and hours of sunshine, SPI is related to precipitation so, ET_0 and SPI can be used to sum up the main information of meteorological factors, they can be used as the indexes reflecting the climate characteristic changes. Table 3 showed the analysis results which were about the sustainability and variation points of ET_0, SPI in Winter wheat growth period and their annual values in wugong region. The results showed that the Hurst indexes of ET_0, SPI in Winter wheat growth period and their annual values were all >0.5. Based on Hurst index theory, ET_0, SPI will still keep the same change tendency with it was in the past within a time in the future.

According to R/S Method, the change points of ET_0 and SPI were diagnosed, annual ET0 and SPI, respectively varied in 1984 and 1987 in wugong region, ET_0 and SPI, respectively varied in 1982 and 1998 in Winter wheat growth period. The diagnosed variation years were not entirely consistent with highs and lows in Fig. 1a, b, 2a and b the reason for this was that from statistical analysis speaking, maximum variation point was a point that fractal characteristic value Hurst index and fractal dimension D_0 changed obviously in two stages of the studied time series which was relative to the analyzed sample points in comparison so, they may not necessarily coincide with highs and lows.

The effect of climate change on Winter wheat yield analysis of climate yield components: The factors which effected food yield were mainly climate and social factors, the food yield change with time can be divided into two parts, one was fluctuation departing this tendency in a short time (climate yield, the part affected by climate factor), the other was keeping a change tendency in a long time (trend yield, the part affected by social factor) (Shi *et al*., 2008):

$$Y = Y(w) + Y(t) \quad (1)$$

Where:

Y = Actual yield (kg hm^{-2})
Y (w) = Climate yield (kg hm^{-2})
Y (t) = Trend yield (kg hm^{-2})

The Straight Line Moving Average Simulation Method was adopted to get the trend yield and climate yield equaled actual yield minus trend yield. The contribution ratio of climate yield was calculated by Eq. 2:

$$\delta = Y(w)/Y \quad (2)$$

The actual yield, climate yield of winter wheat and the change tendency of the contribution ratio of climate yield were analyzed as shown in Fig. 3.

The Fig. 3a has indicated that it totally had an obviously increasing tendency for Winter wheat yield, the yield has been increased 4572.2 kg hm^{-2} compared the early ten years in 21st century with the 40 sec in 20th century, the growth rate has been reached to 465.8%. The climate yield totally presented a little decreasing

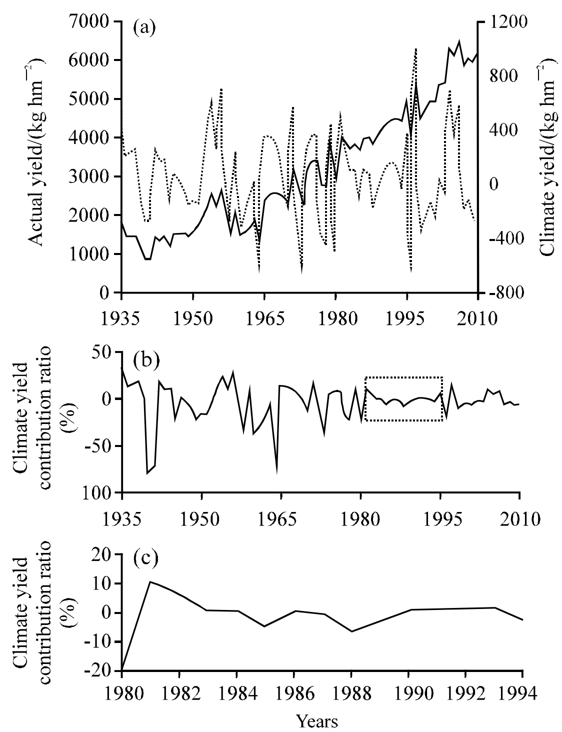

Fig. 3: a) The change trend of winter wheat actual yield and climate yield (the dash line is the climate yield, the bold line is the actual yield); b) the change trend of climate yield contribution ratio; c) the graph of partial enlargement in b from 1983 to 1997

tendency, climate warming has had a negative effect on the increase of Winter wheat yield. From the fluctuating curve, the actual yield and climate yield totally have had a decrease tendency from 1935-1941 and 1956-1961. The natural and human factors were the main effects on yield. In analysis of the natural factor, SPI all had a downtrend from 1935-1941 and 1956-1961, climate was trend to develop into drought. In analysis of the human factor, the war in China reflected mainly the effect on agricultural production during 1935-1941; the early period of China society construction led to an instability of agricultural production during 1956-1961.

From the Fig. 3b and c can be shown that the contribution ratio of climate yield changed from 78.54-34.53% during 1935~1982, among them 1940 (-78.54), 1941 (-71.33) and 1964 (-72.19%) played a leading role (the absolute value of contribution ratio were >50%). Yield is mainly effected by climate factor and human factor (it is main technical level, controllable agricultural production investment, policy mechanism, etc.) (Wu and Zhao, 2010). So, climate factor had a great effects on Winter wheat yield in Wugong region but human factor was acted the leading role in this period. During 1983~2010, the contribution ratio of climate yield changed from to -18.68 to 17.56%, there were 3 years whose absolute values of contribution ratio were >10% which were, respectively 1997 (17.56), 2004 (10.68) and 1996 (-18.68%). This stage, the effect degree of climate change on Winter wheat declined in Wugong region. In other words, the capacity of crop production against climate change gradually enhanced which may benefited from the development of productivity. This phenomenon was coincidence with the rural household contract responsibility system in China and basically with the technology development on field irrigation, variety improvement and also closely related with the large increase of the investment into agricultural production.

The path analysis of climate change on Winter wheat yield: Select out the monthly average temperature (x_1), monthly maximum temperature (x_2), monthly minimum temperature (x_3), hours of sunshine (x_4), monthly average wind speed (x_5), monthly mean relative humidity (x_6) and precipitation (x_7) as weather factors that climate change impacted on Winter wheat yield. The analysis results of each weather factor and yield were showed in Table 3 and 4. Based on the related analysis between yield and each weather factor, researchers have acquired that except for maximum temperature and relative humidity, the simple correlation coefficients between yield and minimum temperature, hours of sunshine, wind speed were respectively, 0.624, -0.401 and -0.518 which all presented an extremely significant level and between yield and average temperature, relative humidity were respectively 0.258 and -0.223 which all showed a significant level. There exists certain degree of correlation between each meteorological factor, most revealed a significant or an extremely significant level. So yield, each weather factor and each single factor exists interaction between each other.

Because there exists strong relation between each meteorological factor, it is difficult to ensure the impact degree of each factor on Winter wheat but this relation can be reflected by path analysis. The direct path coefficient illustrated the direct impact degree of each weather factor on crop yield (Yuan and Yun, 2007). From Table 3, researchers can indicate that the direct effect coefficient of minimum temperature and precipitation on Winter wheat yield were separately 0.648 and -0.293 which all reached an extremely significant level; the direct effect coefficient of wind speed and maximum temperature on Winter wheat yield were separately -0.205 and -0.240 which all showed a significant level. The minimum temperature increased yield, the other weather factors decreased yield, the weather factor adding yield was still minimum temperature (the direct path coefficient was 0.265) but among the weather factors dropping off yield, the impact of relative humidity on yield was the lowest (the direct path coefficient was -0.018), the effect of precipitation on yield was the highest (the direct path coefficient was -0.293), the negative effect size order of weather factors on yield was $x_7>x_2>x_5>x_4>x_1>x_6$. In general, precipitation is the main water source of plants growth. But as far as Wugong region is concerned, there was a negative correlation between Winter wheat yield and precipitation, according to the Mann-Kendall tendency analysis in Winter wheat growth period, declining precipitation led to shortage of soil water supply so, Winter wheat growth and output were seriously affected. According to law of water vapour diffusion, there exists a negative correlation between water vapour diffusion rate and the resistance in the water vapour diffusion process and a correlation is observed between wind speed and the resistance in the process of water vapour diffusion when wind speed decreased significantly, water vapour diffusion resistance was trend to increase and evapotranspiration rate had a downtrend thus, Winter wheat growth was restrained. The significantly increasing minimum temperature was conducive to relieve the impact of hypothermy on Winter wheat and made the benefits of overcoming Winter and increasing output for wheat. The significantly decreasing maximum temperature had a negative correlation with Winter wheat yield which had an inhibitive impact on yield.

After researching the indirect effect of each weather factor on Winter wheat yield, the results were listed in Table 5, average temperature by minimum temperature made the greatest action on Winter wheat yield while it made the greatest inhibitory action by maximum temperature, their indirect-effect coefficients were respectively 0.34 and -0.159; maximum temperature by minimum temperature had a great positive effect on Winter wheat yield its indirect-effect coefficient was 0.25; minimum temperature directly impacted on Winter wheat yield; hours of sunshine by minimum temperature had a great negative effect on Winter wheat yield, the indirect-effect path coefficient was -0.264; wind speed by minimum temperature had an obviously negative effect on Winter wheat yield its indirect-effect path coefficient was -0.274; precipitation by the other weather factors had some effect on Winter wheat yield but was very feeble.

Table 4: Correlation analysis among individual index and directly path coefficient

Factor	x_1/°C	x_2/°C	x_3/°C	x_4/h	x_5/ (m sec^{-1})	x_6	x_7/mm	y
x_1	1	-	-	-	-	-	-	0.258*
x_2	0.664**	1	-	-	-	-	-	0.035
x_3	0.535**	0.385**	1	-	-	-	-	0.624**
x_4	-0.206	0.033	-0.408**	1	-	-	-	-0.401**
x_5	-0.307**	-0.195	-0.429**	0.363**	1	-	-	-0.518**
x_6	-0.364**	-0.313**	-0.151	-0.301**	0.020	1	-	-0.048
x_7	-0.253*	-0.163	0.065	-0.139	0.233*	0.255*	1	-0.223*

** is extremely significant at the 1% level; Positive stands for increasing tendency, negative stands for decreasing tendency

Table 5: Path analysis results between crop yield and weather factors

Factor	Decision-making coefficient (%)	Direct effect coefficient	Indirect effect coefficient							
			x_1-y	x_2→y	x_3→y	x_4→y	x_5→y	x_6→y	x_7→y	Sum of indirect effect coefficient
x_1	7.85	0.097	-	-0.159	0.346	0.025	0.063	0.007	0.074	0.356
x_2	-7.42	-0.240*	-0.064	-	0.250	-0.004	0.040	0.006	0.048	0.276
x_3	38.88	0.648**	-0.052	-0.092	-	0.049	0.088	0.003	-0.019	-0.023
x_4	8.17	-0.120	0.020	-0.008	-0.264	-	-0.074	0.005	0.041	-0.280
x_5	17.07	-0.205*	0.030	0.047	-0.278	-0.043	-	-0.001	-0.068	-0.313
x_6	0.14	-0.018	0.035	0.075	-0.098	0.036	-0.004	-	-0.075	-0.031
x_7	4.47	-0.293**	0.025	0.042	0.042	0.017	-0.048	-0.005	-	0.073

x_j (j = 1-7) separately stand for monthly average temperature, monthly average maximum temperature, monthly average minimum temperature, hours of sunshine, monthly average wind speed, monthly mean relative humidity and precipitation; y stands for winter wheat yield; * is significant at the 5% level; ** is extremely significant at the 1% level; positive stands for increasing tendency, negative stands for decreasing tendency

The complex relationship between each weather factor and yield was made clear by direct-effect coefficient and indirect-effect coefficient but in the final decision-making in order to indicate the comprehensive decided ability of each weather factor on yield, an overall indicator need to be put forward so, decision-making coefficient arrived to us (Yuan and Yun, 2007). After analyzing the comprehensive decided ability of each weather factor on Winter wheat yield, the comprehensive effect of each weather factor on yield can be ranked as follow (Table 5): minimum temperature>wind speed>hours of sunshine>average temperature>precipitation>relative humidity>maximum temperature. The ranked result shows that the comprehensive effect degree of each weather factor on Winter wheat yield thus minimum temperature had the greatest comprehensive decision ability on yield, the decision-making coefficient was 38.88% so, it was the major determiner. The comprehensive decision ability of wind speed on yield was lower than minimum temperature, its decision-making coefficient was 17.07%. The decision-making coefficient of maximum temperature on yield was -7.42% so, it was the major restrained factor.

To sum up, having researching the comprehensive impact of each weather factor on yield, researchers come to a conclusion that in Wugong region, the major yield-affected meteorological factors were minimum temperature, wind speed, hours of sunshine and maximum temperature, and can be combined with other meteorological factors on Winter wheat yield effect.

RESULTS AND DISCUSSION

Rising temperature and declining precipitation made the climate tend to warm-dry type in Wugong region but change tendency was not significant, this type of climate led to soil moisture reduction and caused declining of the productive forces which coincides with literature research results (Yao *et al*., 2005). According to Hurst index analysis of each weather factor, the coming climate change tendency will still keep the same with it was in the past which will have adverse impact on winter wheat production. So, one should enhance water conservancy infrastructure construction to protect agricultural production, the other should cultivate and select crop variety which is suitable for climate change in variety selection and pay attention to the choice of adaptability and resistance varieties In the production, should improve dry or water saving cultivation techniques, etc. in order to increase water use efficiency, enhance the capacity of region food production against climate change, especially resist the negative effect caused by climate change and obtain optimum yield.

Pathway analysis shows that each weather factor have an impact on Winter wheat yield through the direct action, indirect effect and comprehensive effect so which evaluate yield through the direct index, indirect index and comprehensive index but the last two kinds of indexes will further analyze in the future research. This study preliminarily analyzed the impact of climate change on Winter wheat yield during the recent 76 years in Wugong region but there were lots of factors to impact on Winter wheat yield, like social production input (farm chemical, fertilizer, electricity, etc.), etc. but this study only studied the impact of climate change on Winter wheat yield in future, the impacts of other factors on Winter wheat yield should be considered, like human factor and crop disease. which can provide much more exact basis for adapting to the climate change and improving agricultural productivity levels in this area. Meanwhile, this study mainly researched relation between mean climate and yield but did not study relation between extreme climate change and yield in the recent years, such as dry and hot wind, waterlogging and drought. In future, researchers should enhance the impact research of the region extreme climate on Winter wheat yield.

CONCLUSION

Minimum temperature was trend to an extremely significant increasing in Wugong region, its change rate was 0.204°C/10a and wind speed, hours of sunshine and ET_0 all had an extremely significant downtrend, their change rate were separately -0.077 m sec^{-1}/10a, -61.984 h/10a and -11.35 mm/10a; minimum temperature had an extremely significant growth trend in Winter wheat growth period, its change rate was 0.248°C/10a and wind speed, hours of sunshine and ET_0 all had an extremely significant downtrend, their change rate were separately -0.085 m sec^{-1}/10a and -28.463 h/10a. The Hurst indexes of ET_0 and SPI (annual value and Winter wheat growth period) were all >0.5 which showed a continual change tendency that is climate developing into aridity in Winter wheat growth period and Wugong region will still continue within a period of time in the future.

The negative impact of climate change on crop production in Wugong region can be mitigated to some extent by human factors. Before the 1980s, climate yield contribution ratio fluctuated from -78.54-34.53%, climate change had a great effect on crop production but human factor was still dominant. Since the 1980s, climate yield contribution ratio has fluctuated from -18.68-17.56%, human factor has had a more effect on food production whose capacity of confronting climate change has advanced. In analysis of the comprehensive effect of each weather factor on yield by path analysis method, the result showed that in Winter wheat growth period, significant rising trend of minimum temperature most decide the growing comprehensive capacity of Winter wheat, the comprehensive decision ability of wind speed on yield took second place, maximum temperature was the main restrictive factors of meteorological phenomena for Winter wheat yield increase and can be combined with other meteorological factors on Winter wheat yield effect.

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