

Quantitative Research on the Relationship between Yield of Winter Wheat and Agroclimatological Resources—the Case Study from Yanzhou District, Shandong Province, China

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Abstract. Agroclimatological resources provide material and energy for agricultural production. This study is aimed to analyze the impact of selected climate factors change on wheat yield over the different growth period applied quantitatively method, by comparing two different time division modules of wheat growth cycle- monthly empirical-statistical multiple regression models (From October to June of next year) and growth stage empirical-statistical multiple regression models (Including sowing stage, seedling stage, tillering stage, overwintering period, regreening period, jointing stage, heading stage, maturity stage) analysis of relationship between agrometeorological data and growth stage records and winter wheat production in Yanzhou, Shandong Province of China. Correlation analysis(CA)was done for 35 years (from 1981 to 2015) between crop yield and corresponding weather parameters including daily mean temperature, sunshine duration, and average daily precipitation selected from 18 different meteorological factors. The results shows that the greatest impact on the winter wheat yield is the precipitation overwintering period in this area, each 1mm increase in daily mean rainfall was associated with 201.64 kg/hm² lowered output. Moreover, the temperature and sunshine duration in heading period and maturity stage also exert significant influence on the output, every 1°C increase in daily mean temperature was associated with 199.85kg/hm² adding output, every 1h increase in mean sunshine duration was associated with 130.68kg/hm² reduced output. Comparing with the results of experiment which using months as step sizes and using farming as step sizes was in better agreement with the fluctuation in meteorological yield, offered a better explanation on the growth mechanism of wheat. Eventually the results indicated that 3 factors affects the yield during different growing periods of wheat in different extent and provided more specific reference to guide the agricultural production management in this area.



1. Introduction

Agro climatic resources named agroclimatological resources refer to the potential of climatic conditions in an area related to the development of agricultural ecosystems, and it is not only a prerequisite for the planting of crops, but also the key factor to the crop yield. It has been proved that meteorological fluctuations in a certain extent even determine the fluctuations of crop yield [1, 2] by affecting development the growth of main organs such as root and stem [6]. Therefore it is very important to study the key factors of wheat production and how these factors affecting the yield.

In 1925, The concept of integral regression has been firstly proposed by Fisher when he studied the relationship between winter wheat yield and precipitation [11]. The method was extended to multiple mapping later, described as that the influence of meteorological factors on yield during the period can be expressed in the form of integral regression over the whole growth period of Crop (from sowing to mature). Since then, it has been widely used to evaluate the impacts of meteorological traits on agricultural production and crop yield [5, 7, 9]. In 2001, Xue Zhengping used multiple regression model for analyze the influence of three factors of light, temperature and precipitation on the yield of 23 provinces in China. In 2004, Xu Weigen used the model to calculate the sensitivity index of precipitation to winter wheat yield in 5 agro climatic regions of Jiangsu province. In 2016 Jia Jianying used a period of ten days as step, based on the principle of integral regression, analyzes the main meteorological factors and the key periods of winter wheat production in the middle, Eastern and Longnan regions, and establishes the dynamic forecasting model of winter wheat yield in the critical period. All the previous studies have enriched the theory of meteorological-yield integral regression model, and a trend from qualitative to quantitative, from rough to precise in application. But it still has certain dislocation with the growth stages of wheat for taking month or ten days as the granularity of time, so that the results ineluctable limit the precision guidance ability of actual agricultural production according to circumstances.

In order to achieve seamless docking with the model of winter wheat production, this paper take Yanzhou District of China as case, construct the multiple integral regression model by using growth stages as step size which reflect the growth and development of winter wheat. Quantify the relationship between the meteorological and yield of winter wheat based on the comprehensive consideration of meteorological factors, and analysis the mechanism of how could meteorological effect on yield in each stage of winter wheat.

2. Materials and Methods

The research materials include meteorological data, growth stage records and corresponding yield data of winter wheat in Yanzhou of Shandong province during 1981-2015. Meteorological data cited the meteorological scientific data posted on the service China network and the project of Bohai grain science and technology demonstration, growth stage records and the corresponding yield data of winter wheat is provided by the Yanzhou Municipal Bureau of agriculture and refer to a database form Chinese planting crops information network which was made by the Ministry of agriculture planting industry management department of development, the records on the network were provided by the database "Chinese Statistical Yearbook", "China Agricultural Statistics" and provincial and county agricultural department.

2.1. Overview of the Study Area

In China, winter wheat and spring wheat are concurrently grown, among them winter wheat acreage accounted for about 84% to 90% of the total area of wheat, mainly distributed in the south of the Great Wall named the Huanghuaihai Winter Wheat Region[7,8]: including all of Shandong, most of Henan, parts of Hebei, Jiangsu, Anhui, Shaanxi, Shanxi, Gansu province. Wheat area and wheat yield accounts for about 45% and 48% of the national total, which is about 44% of the total crop area in the whole region, and is the main wheat producing area in china.

Yanzhou subordinate to the Shandong city of Jining, located between $35^{\circ} 43' 17''$ E— $35^{\circ} 43' 17''$ E, and $116^{\circ} 35' 21''$ N— $116^{\circ} 45' 01''$ N, in southwest of Shandong Province (Figure 1). It is

known as a typical demonstration base of Huanghuaihai Winter Wheat Region, also the national commodity grain production base. Winter wheat planting area was 420 thousand acres in 2012, the yield of wheat was also in the leading position in Shandong province owing to the city's renovation system.

The climate of Yanzhou is a warm temperate semi humid climate zone, with windy and drought spring, rainy summer, cool and mild autumn, dry and cold winter. Winter wheat is the main grain crop in the region, in 2015 the latest statistics showed the area of winter wheat was 425966 acres.

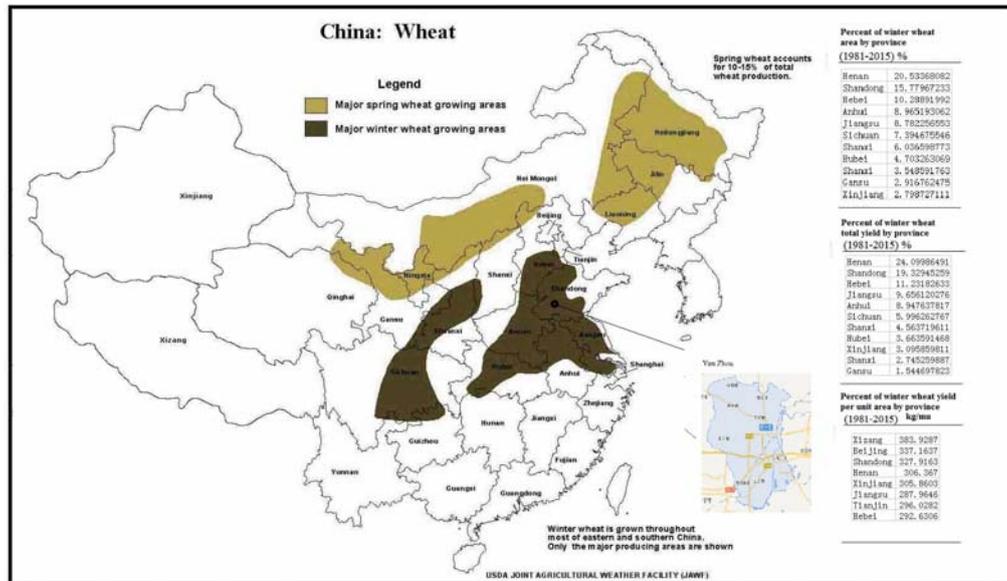


Figure. 1 Geographic location and spatial distribution of sample points of the study area

2.2. Data Acquisition

Table 1. Phase of the relationship between meteorological factors

Related items	correlation coefficient	Related items	correlation coefficient
Precipitation & sunshine duration	0.2381	Mean pressure & temperature	-0.8851
Minimum relative humidity & sunshine duration	-0.5755	Daily maximum pressure & temperature	-0.9017
Minimum relative humidity & precipitation	0.3080	Daily minimum pressure & temperature	-0.8641
Mean relative humidity & sunshine duration	-0.4388	Daily maximum temperature & temperature	0.9781
Average relative humidity & precipitation	0.2655	Daily minimum temperature & temperature	0.9771
The average water vapor pressure & temperature	0.9100	Daily precipitation & temperature	0.0710
Small evaporation & temperature	0.8544	sunshine duration & temperature	0.1710

Note: [0.00, ± 0.30] related micro; [0.30, ± 0.50] real; [±0.50, ±0.80]significantly correlated; [± 0.80, ± 1] highly correlated

2.2.1. Meteorological Data Acquisition. The meteorological data material means Daily meteorological data collected by a set of ground monitoring station at No. 54916 Station which were made according to the "national ground climate data (1961-1990) the relevant provisions of statistical methods" and "meteorological observation standard", including the following elements: average pressure, maximum pressure, minimum pressure, average temperature, daily maximum temperature, daily minimum temperature, average vapor pressure, average relative humidity, minimum relative humidity, 20-20 precipitation, evaporation, large evaporation, sunshine duration.

First of all, 13 kinds of meteorological factors should be preliminarily processed to eliminate the missing data and outliers. Then, representative characteristic factors would be selected from correlation base on the results of analyzing as shown in table 1.

Obviously, it showed that temperature was highly correlated with the pressure and evaporation, and the humidity has a significant correlation with sunshine duration. It is supposed to selected three factors from all 13 factors which has the lowest correlation, daily mean temperature, sunshine duration, and average daily precipitation respectively, as the main indicators of research about the relationship between winter wheat yield and meteorological factors.

2.2.2. Growth Stage Records Acquisition. Growth stage means in agricultural production, each kind of crops have certain growth stage and some farming time, is the attribute of the crop itself. Like the whole growth period of winter wheat have been divided into sowing, seedling, tillering, overwintering, reviving, jointing, heading and maturity period, every stage adapts to specific optimum meteorological environment, in the long-term production practice, Yanzhou has formed a complete set of farming records criterion as shown in the table 2.

Table 2. Shandong Yanzhou area farming records

No	stages	conditions	meteorological threshold	time range
C1	Before Sowing	Planting date of more than 50% of the city	Daily average temperature of 15-20°C, accumulated temperature before winter 550-650°C	October 5 to October 15th
C2	Sowing - emergence	More than 50% of the first true leaf of wheat exposed surface 2-3 cm	The average temperature of 14-16 °C, sowing to the accumulated temperature of 100-120°C	5-8 days after sowing
C3	Emergence - tillering	50% above the first tiller exposed leaf sheath 2 cm	The average daily temperature of 12-15 °C, >18°C tillering inhibited	From late October to early November
C4	Tiller -winter	Stop the growth of Wheat Seedling	Before winter, the average temperature stabilized to 3-0°C	Mid December
C5	Winter - Green	More than 50% of the following winter wheat continue to develop	When the temperature rose to 3 °C	Late February
C6	Reviving-jointing	More than 50% of the stem of the first section of the exposed 1.5~2cm	The average temperature of 12-16°C for growth	March 25th -4 month 5
C7	Jointing - heading	50% more than half of the wheat leaf exposed in the sheath	Is sensitive to illumination, the average temperature of >15 °C	From late April to early May
C8	Heading-maturity	When the kernel begins to harden	Suitable temperature 18-22 °C	Mature in mid June

It was clearly showed in table 2 that the winter wheat growth period can be divided into 8 stages (C1-C8 in Table 2) from October to June of the following year, totally duration was 9 months. And it

was definitely that the period of the beginning of the October to the corresponding sowing day could be sowing period, after sowing, according to the physiological characteristics of winter wheat, there were material to recording the winter wheat seedling start date, tillering start date, winter start date, reviving start date, jointing start date, heading start date, and harvest date. It is necessary to use specific farming records because advance or delay to annual farming are ineluctable [3, 15].

2.2.3. Winter Wheat Yield Data. From 1981 to 2015, the yield per unit area of Yanzhou district, Jining city, Shandong province of China, is as shown in Figure 2. Obviously, the yield per unit area in Yanzhou is higher than others district of Shandong Province, while the per unit area yield in Shandong is higher than that in the whole country. The average yield per unit area of Yanzhou is $6343.44\text{kg}/\text{hm}^2$, while Shandong and China is $4782.83\text{kg}/\text{hm}^2$ and $3877.67\text{kg}/\text{hm}^2$ respectively. The average yield per unit area of Yanzhou is higher than that of Shandong province and national by 32.63% and 63.59% respectively. It can be consider that the yield per unit area of winter wheat in Yanzhou represents the higher level in China. The trend of yield per unit area of winter wheat has fluctuated upward overall, but the increase in the last 10 years has narrowed significantly. Winter wheat in this area entered a stable period of production.

Data of winter wheat yield were obtained from Yanzhou Municipal Bureau of Agriculture, results of statistics showed that the yield of winter wheat in Yanzhou district had an overall upward but not strictly increasing trend with different levels of yield fluctuation during the study period 1981 – 2015, but overall yield was higher than the national average in the same period. Specific changes in yield as shown in figure 2, the lowest yield was recorded in 1982 ($4275\text{ kg}/\text{hm}^2$) and peaked in 2015 ($8117.7\text{kg}/\text{hm}^2$).

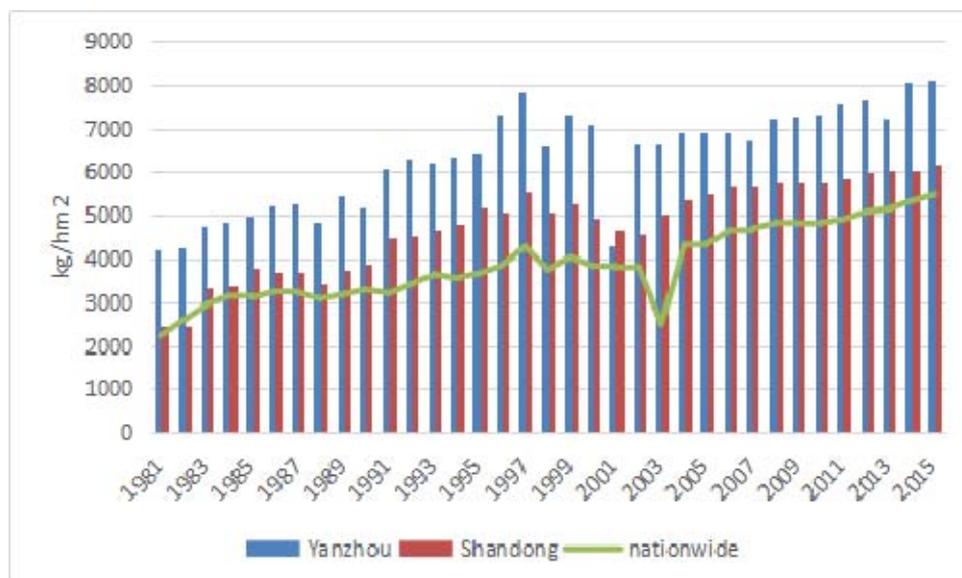


Figure. 2 1981-2015 winter wheat yield histogram

2.3. Description and Analysis of Meteorological Factors

The description and analysis for mean growth stage and monthly meteorological factors were shown in Table 3 and Table 4.

Statistical data for 35 years in Yanzhou area showed that mean air temperature ranged from $-0.36\text{ }^{\circ}\text{C}$ (C5) to $21.13\text{ }^{\circ}\text{C}$ (C8), mean precipitation ranged from 0.21mm (C5) to 1.94mm (C8), and mean sunshine duration ranged from 5.37h (C4) to 8.22h (C8). Based on growth periods, the average value of sowing temperature was $17.01\text{ }^{\circ}\text{C}$, the maximum temperature was $20.30\text{ }^{\circ}\text{C}$, the lowest temperature was $13.30\text{ }^{\circ}\text{C}$, the average sunshine was 6.5 hours per day, during sowing to emergence

date, the average temperature was 15.76 °C, with accumulated temperature of 120 °C, from seedling to tillering date average temperature was 13.19 °C, with accumulated temperature of 210 °C, during overwintering to tillers, the average temperature is 5.39 °C, illumination hours reached the lowest with the average of 5.37 hours, when it came to winter green, the average temperature was -0.36°C, and precipitation reached the lowest average 0.21mm per day, returning to jointing stage the average temperature was 7.34 °C, the average temperature from jointing to heading was 14.84 °C, the average rainfall was 0.96mm every day, heading to harvest the average temperature was 21.13 °C, also the highest temperature in whole life cycle , and the average illumination was 8.2h/d (Table 3).

Table 3. 1981-2015 Shandong Yanzhou area meteorological factors descriptive analysis base on growth stage

MF	Description	C1	C2	C3	C4	C5	C6	C7	C8
temperature °C/day	average value	17.01	15.76	13.19	5.39	-0.36	7.34	14.84	21.13
	standard deviation	1.72	1.77	1.86	1.37	0.72	1.10	0.96	0.81
Precipitation mm/day	average value	1.19	1.15	0.65	0.63	0.21	0.62	0.99	1.94
	standard deviation	1.76	2.07	0.77	0.78	0.18	0.48	0.80	1.12
Sunshine duration h/day	average value	6.55	6.54	6.61	5.37	5.44	6.36	7.88	8.22
	standard deviation	2.18	1.99	1.31	1.35	0.87	1.11	1.09	0.99

The analysis based on the month showed that in January there had the lowest temperature, least rainfall and shortest sunshine duration (the average temperature was 0.96°C, the average precipitation was 0.18mm, average sunshine time was 5.12h). On the contrary, the temperature, precipitation reached the highest level (an average of 25.22 °C, 2.76mm) in June. In addition the longest sunshine duration is 8.2h which appeared in May.

Table 4. 1981-2015 Shandong Yanzhou area meteorological factors descriptive analysis based on month

MF	Description	October	November	December	January	February	March	April	May	June
temperature °C/day	average value	14.86	7.13	0.57	-0.96	2.14	7.91	14.85	20.40	25.22
	standard deviation	1.14	1.24	0.97	1.16	1.62	1.47	1.01	0.88	0.81
Precipitation mm/day	average value	0.93	0.76	0.29	0.18	0.38	0.60	1.09	1.95	2.76
	standard deviation	0.81	0.96	0.29	0.25	0.32	0.58	0.81	1.27	1.90
Sunshine duration h/day	average value	6.52	5.70	5.14	5.12	5.54	6.63	7.91	8.20	7.64
	standard deviation	1.27	1.46	1.39	1.01	1.28	1.10	1.01	1.09	1.25

From the comparison of Table3 and Table4, it found that the features of meteorological factors were different in the two time division model, this was mainly because that the winter wheat growth cycle was not uniform, for example, the wintering period of winter wheat up to 2-3 months, while the winter wheat seedling time is only limit in 1-2 weeks. Especially at the beginning and end of the winter wheat planting process, it wasn't sown at the beginning of October, nor matured at the end of June. In the Yanzhou region, the monthly model covers the winter wheat growth cycle resulting in distortion of analysis results in some extent. Obviously, it was more accurate when it divided by winter wheat growing stages. In addition, it was necessary to comprehensive compare different temporal scales of climate conditions to optimize the multiple regression model [4, 5].

3. Model

3.1. Meteorological Yield Model

The growth and yield of winter wheat were determined by natural resources, technology and material conditions [12]. Natural environmental factors such as weather and natural disasters are important indicators to determine whether a region is suitable for the crop growth. Before setting up the model of the influence of weather on the yield, it should first decompose the yield into the actual yield and extract the meteorological yield, such as formula (1):

$$y = y_t + y_w + \Delta y \quad (1)$$

Among them, y is the actual yield recorded, y_t is generally known as the trend of production or social and economic output, affected by the factors such as management mode, cultivation technology, variety improvement and so on, its trend is consistent with the scientific progress of agricultural production, y_w is the crop yield fluctuation caused by weather, the corresponding component of yield is generally called the meteorological yield, Δy is generally called fluctuating yield, represent the fluctuation of yield caused by the occurrence of discontinuous factors such as pests, diseases and human error [13].

Generally, the methods of decomposing meteorological yield include moving average method, polynomial regression method, linear simulation method and so on. Formula (1) shows that in addition to the long-term trend, and also the output fluctuation is caused by meteorological factors and other accidental factors. This paper uses the method of moving average combined with two degree polynomial apply for meteorological yield analysis.

First, the orthogonal quadratic polynomial was used to solve the long term trend of winter wheat yield in Yanzhou region, which can effectively express the smooth trend in common wheat yield limited by natural resources, technology level and the material conditions. Then fitting the actual output by moving average method, the sliding window size is 11, the principle is to measure the output data of the current year by weighted average of the yield of first five years, the last five years and this year, In this method, the fluctuation of output caused by accidental factors such as diseases and insect pests in the interval is estimated. Finally, the difference between the two is the meteorological yield. The specific process is as follows:

Winter wheat yield

Such as formula (2) to build a polynomial of the two:

$$f(x) = p_1 * x^2 + p_2 * x + p_3 \quad (2)$$

Solved:

$$P_1 = -2.733, P_2 = 1.102e+04, P_3 = -1.11e+07$$

The fitting results shown as below, from 1981-2005 years, changes in the yield of winter wheat continued to show growth trend, due to breeding, cultivation technique innovation, and also inseparable from other strategies of scientific management. Until 2005, the trend of yield growth slowed down, and began to become more stable, indicates that the current technology innovation for the yield increase is close to natural resources and production load in the region. It indicate that the yield began to enter the stable output period.

(1) Moving average yield

The sliding window is chosen to be 11, which can be used to calculate the trend yield in a given year.

$$\bar{y}_t = \frac{\sum_{i=t-5}^{t+5} y_i}{11} = (y_{t-5} + y_{t-4} + y_{t-3} + y_{t-2} + y_{t-1} + y_t + y_{t+1} + y_{t+2} + y_{t+3} + y_{t+4} + y_{t+5})/11 \quad (3)$$

As shown in Figure 3, the moving average yield can reduce the fluctuation caused by the random factors compared with the actual production, and optimize the formation of a small range of obvious trend compared with the two polynomial fitting results, reflecting the output fluctuation within a certain stage of the natural factors such as weather changes, and also created the foundation for solving the stability of meteorological yield. Moreover, it also reveals a fact that there is a certain cycle in the trend of yield.

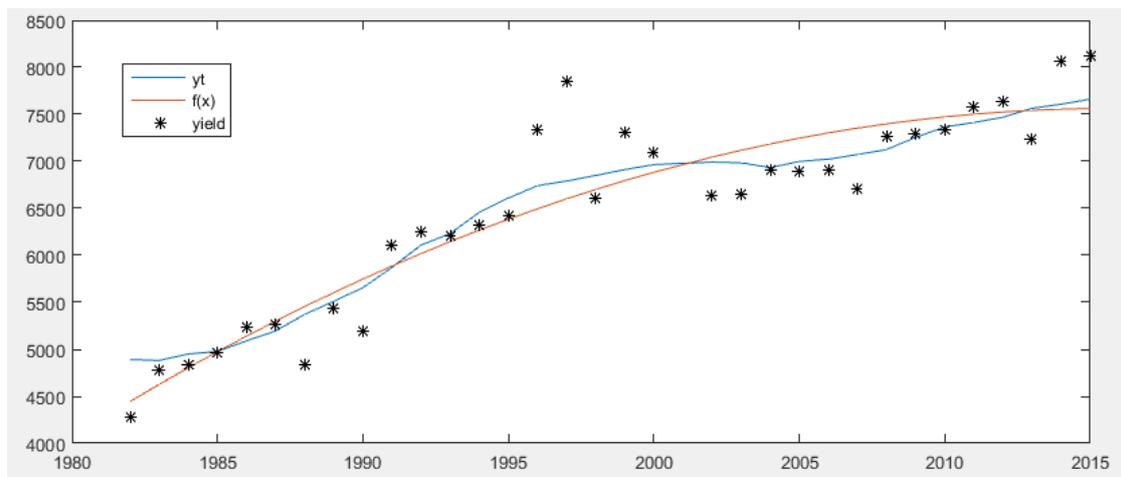


Figure. 3 Trend of Yanzhou in Shandong Province Winter Wheat Production from 1981 to 2015

(2) Solving meteorological yield

Such as formula (4) for meteorological yield:

$$y_w = f(x) - \bar{y}_t \quad (4)$$

Compared with the difference between the actual output and the trend yield, this method can eliminate the error caused by the uncertain factors, and provide a more stable reference for the separation of meteorological yield.

3.2. Integral Regression Model

Regression (regression analysis) is a statistical analysis method to determining the quantitative relationship between two or more variables. In this study, the meteorological yield is a function of the relationship among sunshine duration, precipitation and temperature, and the meteorological factors which have the different effects on the yield of wheat in different periods, the British Fisher proposed the influence of meteorological factors on yield during the whole growth period of crops can be expressed in the form of integral regression. The whole growth period of the crop is divided into T segments, and the yield of winter wheat can be expressed by the following model showed in formula (5):

$$y_w = \alpha_0 + \int_0^T a_{1j}(t)x_1(t)dt + \int_0^T a_{2j}(t)x_2(t)dt + \int_0^T a_{3j}(t)x_3(t)dt \quad (5)$$

The y_w is called meteorological yield, α_0 is a constant, T as the count of divided stages, the farming model is divided into 8 months, the model is divided into 9, a_1 means the temperature coefficient for each stage, $x_1(t)$ is a function of temperature, a_2 represents illumination coefficient in each stage, $x_2(t)$ shows sunshine duration function, a_3 defines the coefficient of precipitation in each stage, $x_3(t)$ is a function of the precipitation .

Take the farming model as an example, this paper will expansion (5) for Non homogeneous linear equation with 25 variables, then the least squares method is used to solve 25 unknowns in the 34 equations.

$$y_{wi} = \alpha_0 + a_{11}x_{11}(i) + a_{12}x_{12}(i) + \dots + a_{1n}x_{1n}(i) + a_{21}x_{21}(i) + a_{22}x_{22}(i) + \dots + a_{2n}x_{2n}(i) + a_{31}x_{31}(i) + a_{32}x_{32}(i) + \dots + a_{3n}x_{3n}(i)$$

The i value range 1-34, n values 8 in farming model, and 9 in month model.

4. Results and Analysis

4.1. Analysis of Farming Model Results

By using least square method, the influence coefficient of three meteorological factors on different stages of wheat yield are obtained, as shown in Table 5. Yield showed a significant negative influence of mean precipitation in the wintering period (-201.64Kg/hm²) and sunshine duration for maturation period (-130.68Kg/hm²), and positive influence of mean air temperature for maturation period (199.85Kg/hm²).

Table 5. Based on analysis of season three factors of influence coefficient

	C1	C2	C3	C4	C5	C6	C7	C8
temperature	-18.88	3.73	5.18	-58.49	76.57	28.54	-29.51	199.85
Sunshine duration	7.68	85.53	20.24	47.50	15.47	28.26	40.79	-130.68
precipitation	45.13	73.06	0.98	-16.57	-201.64	49.26	36.39	34.40

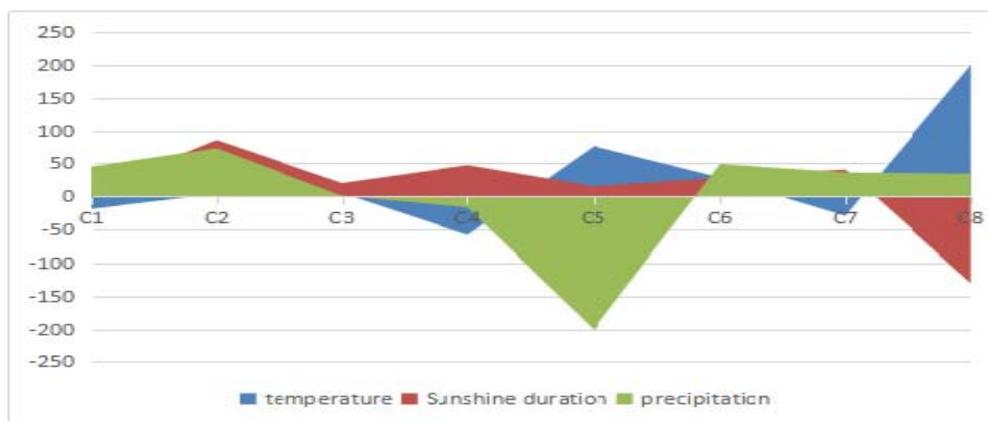


Figure. 4 distribution of sensitive analysis three factors based on farming

C1 (before sowing stage):Yield was more sensitive to precipitation change, for 1mm increase in precipitation, yield was increased by 45.12kg/hm², and the temperature had negative effect on the yield, for 1 °C increase in temperature, the yield decreased by 18.88kg/hm². It has been proved that it is easy to form a flourishing leggy seedlings before winter if sowing early and with high temperature at seedling stage, not only consumes a lot of soil nutrients, but also have side effects, for instance

accumulated less sugar, weakened to frost resistance, prone to winter frost, and seedling death serious [10].

C2 (sowing stage to seedling stage): The germination process of the seeds need a warm, moist environment, as the results shows that for 1mm increase in mean daily precipitation, yield increased by 73.06 kg/hm², and 1 h increase in sunshine duration the yield increased by 85.53 kg/hm². From Table 3 and Table2 we know that the average temperature in Yanzhou was 15.76 °C (C2,Table3), exactly meet the optimum temperature 14 to 16 °C (C2,Table2) for the period of seedling stage, so the output fluctuation of temperature sensitivity is small, also shows that the climate of region meet the needs of the growth stage temperature of winter wheat. The correlation coefficient between sunshine and temperature was 0.25, so the increase of sunshine duration was helpful to the increase of surface temperature, which had positive effect on wheat germination.

C3 (seedling stage to tillering stage):It has shown that the average temperature is 13.19 °C (C3,Table 3), which also meet the most suitable temperature range of 12-15 °C (C3,Table 2), so the result reflect that the yield is not sensitive to meteorological changes within the appropriate range. Meanwhile, the sunshine duration and precipitation are also within the appropriate range.

C4 (tillering stage to overwintering period): Average temperature of this period is 5.39 °C, and has a negative effect on output, when the temperature is raise for 1°C, the yield decreased by 58.49kg/hm². Growth mechanism of winter wheat showed that the tiller would not occur when the average daily temperature was below 3°C, but growth stable and strong at 6 - 13°C, and cause leggy tiller when higher 13°C. Wheat tillering also requires adequate illumination, which can promote the formation of new organs, for 1h longer sunshine duration, the yield increased by 47.50kg/hm².

C5 (overwintering period to returning green stage): The average temperature is -0.36 °C(3 °C for the biological zero) and has a positive effect on the yield of winter wheat, every increase of 1°C temperature, the yield increased 76.57kg/hm². It has been proved that when temperature lower than 0 °C for a long time (>5days), if accompanied with increasing precipitation easily lead to freezing [13]. It is revealed that each 1mm increase of precipitation the yield decreased by 201.64 kg/hm², make precipitation in this period become the most sensitive meteorological factors to the yield of winter wheat in Yanzhou.

C6(returning green stage to jointing stage): High temperature is favorable to increase photosynthesis production during turning green and jointing stage, the results shows that the increases of temperature and sunshine duration are conducive to output increased (1h increase in sunshine duration, yield increased 28.26kg/hm², 1mm increase of precipitation, yield increased by 49.26kg/hm²). The winter wheat growth mechanism showed that the meteorological conditions of high temperature and enough sunshine duration accelerated the growth rate of wheat and accumulation of photosynthetic products.

C7 (jointing stage to heading stage): With an average suitable temperature, the shift of temperature had a no effect on yield. The winter wheat planting experience shows that the stem, leaf, spike and tiller of wheat grow rapidly at the same time (from jointing to heading period), so it can be normal heading and flowering if adequate sunshine time can be ensured.

C8 (heading stage to maturity stage), In this stage, the average temperature is 21.13°C, for 1°C increase in temperature, the yield increased by 199.85kg/hm², at the same time the heading period was sensitive to sunshine duration, with each increase of 1h, the yield decreased by 130.68kg/hm². It has been proved by practice that during the flowering and filling period, adequate sunshine duration can ensure the normal flowering and pollination of wheat and promote the maturation of grain filling.

To sum up, meteorological-yield multiple integral regression model take growth stage as step, the experimental results are consistent with the practice of agricultural production, and have a powerful illustration to the mechanism.

4.2. Model Results Analysis

The constant coefficient of the model is -2181.02, and the three factors are shown in the following table 6:

Table 6. Table three factor influence coefficient of the month model

	Oct	Nov	Dec	Jan	Feb	Mar.	Apr.	May	June
temperature	-101.79	-41.57	7.73	27.43	4.19	53.56	11.65	7.80	81.22
Sunshine duration	32.90	-11.08	-5.24	11.22	-21.35	-44.86	139.36	66.59	-39.27
precipitation	114.45	-66.78	-317.26	-86.01	-371.28	210.87	148.63	65.02	-50.25

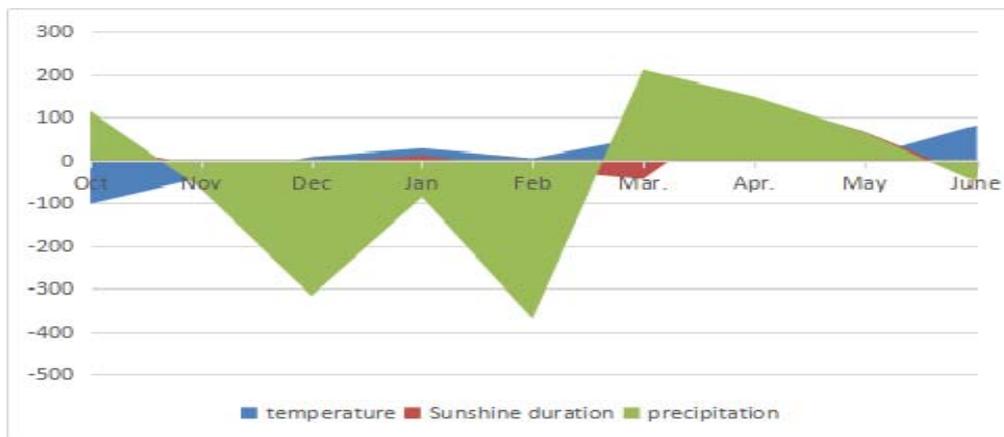


Figure. 5 The distribution of the three factors influence coefficient in the month model

As seen from the above chart, in October, precipitation, sunshine duration has a positive effect on yield while temperature has a negative effect. The temperature increased by 1°C, the yield decreased by 101.79 kg/hm², and the precipitation increased by 1mm, the yield increased by 114.45 kg/hm². From November to February, the precipitation has become the main factor of yield fluctuation [14], enlarge the sensitivity to precipitation when it compared with the growth stage model. From March to May precipitation has a positive effect on yield increase. In March, with 1mm increase of precipitation, the yield increased by 210.87 kg/hm². In June, there was a negative effect of sunshine duration and precipitation on the yield of wheat. Compared with the farming model, the effect of sunshine duration is weakened.

In actual agricultural production, winter wheat was sown in mid October and harvested in early June. Therefore, the regression model covered by the month is more than the actual production, causing redundant statistics of meteorological factors. It reflect inadequate understanding of the month model, and restrictions on the actual production ability when compared with the growth of winter wheat farming model.

4.3. Comparative Analysis

The monthly model is consistent with the agricultural model in some respects, but the agricultural model is absolutely more precise. Compare the two kinds of fitting results with the actual meteorological yield explore that the correlation coefficient of month model with the actual yield is 0.7, and the fitting results with the actual yield farming model related coefficient is 0.843. It indicates that the multivariate integral farming regression model reflect meteorological changes on yield fluctuation in growth stage, establish the foundation for future yield prediction.

5. Conclusions and Discussion

Firstly, this paper fully survey the relationship between meteorological factors and winter wheat yield , selected daily mean temperature, daily precipitation, sunshine duration as the three main meteorological indicators by the correlation coefficient .

Second, based on the existing production decomposition methods, it determine the meteorological yield through the methods of moving average combined with two orthogonal polynomial regression to eliminate external unneeded influence factors such as pest yield fluctuations.

To reflect the growth and development of winter wheat, take growth stage as step, investigate the quantitative relationship between Yanzhou meteorological and winter wheat yield by multiple regression model, analysis the sensitivity of winter wheat yield to different extremes of temperature, like sunshine duration and precipitation by solving coefficient. Experimental results show that the farming model is more practical to meet the agricultural production, and has a certain meaning in guiding significance for the farming production decision than the month model.

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References

- [1] Haris A A, Kumari P, Chhabra V, et al. Modeling the impact of anticipated climate change on wheat yields in two different agro-climatic zones of eastern India [J]. *Journal of Agrometeorology*, 2011, 13(2): 116-118.
- [2] Gouache D, Bouchon A S, Jouanneau E, et al. Agrometeorological analysis and prediction of wheat yield at the departmental level in France [J]. *Agricultural & Forest Meteorology*, 2015, s 209–210: 1-10.
- [3] Wit A D, Baruth B, Boogaard H, et al. Using ERA-INTERIM for regional crop yield forecasting in Europe. [J]. *Climate Research*, 2010, 44(1): 41-53.
- [4] Chauhan V S, Shekh A M, Dixit S K, et al. Yield prediction model of rice in Bulsar district of Gujarat. [J]. *Journal of Agrometeorology*, 2009, 11(2): 162-168.
- [5] Sudharsan D, Adinarayana J, Reddy D R, et al. Evaluation of weather-based rice yield models in India [J]. *International Journal of Biometeorology*, 2013, 57(1): 107.
- [6] Chipanshi A, Zhang Y, Kouadio L, et al. Evaluation of the Integrated Canadian Crop Yield Forecaster (ICCYF) model for in-season prediction of crop yield across the Canadian agricultural landscape [J]. *Agricultural & Forest Meteorology*, 2015, 206: 137-150.
- [7] Xu Jianwen, Ju Hui, Mei Xurong, et al. Simulation on potential effects of drought on winter wheat in Huang-Huai-Hai Plain from 1981 to 2010[J]. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, 2015, 31(6): 150—158. (in Chinese with English abstract)
- [8] Wang Hong, Chen Fu, Shi Quanhong, et al. Analysis of factors on impacting potential productivity of winter wheat in Huanghuaihai agricultural area over 30 years [J]. *Transactions of the CSAE*, 2010, 26(Supp.1): 90-95. (in Chinese with English abstract)
- [9] Xu Shiwei, Yu Wen, Liu Shuyun, Scott Zhang, et al. The Impact of Meteorological Factors on the Winter Wheat Yield—the Case Study from Weishan County, Shandong Province [J]. *Journal of Agricultural* , 2013, (10): 45-51.(in chinese)
- [10] Zhang Huanjun, Yu Hongyan, a sword, Ding Weixin. Effect of sowing date on agronomic, physiologic and yield indicators of wheat in North Henan Province [J]. *Chinese Journal of Eco-Agriculture*, Aug. 2012, 20(8): 1030–1036 .(in chinese)
- [11] Fisher R A. The Influence of Rainfall on the Yield of Wheat at Rothamsted [J]. *Philosophical Transactions of the Royal Society B*, 1925(213): 89-142.
- [12] Xing Suli, Zhang Guanglu, et al. Analysis of the winter wheat yield components and causes under the extreme climatic conditions [J]. *Transactions of the CSAE*, 2005, (S1): 212-214.

- (in chinese)
- [13] Wang Huifang, Gu Xiaohe, Dong Yingying, et al. Monitoring freeze injury and growth recovery of winter wheat based on change vector analysis [J]. Transactions of the CSAE, 2011, 27(11): 141–150. (in Chinese with English abstract)
 - [14] Huang Ling, Gao Yang, Qiu Xinqiang, et al. Effects of irrigation amount and stage on yield and water consumption of different winter wheat cultivars [J]. Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE), 2013, 29(14): 99-108. (in Chinese with English abstract)
 - [15] Yang Jianying, Mei Xurong, Liu Qin, Yan Changrong, He Wenqing, Liu Enke, Liu Shuang. Variations of winter wheat growth stages under climate changes in northern China [J]. Chinese Journal of Plant Ecology, 2011, (06): 623-631.(in chinese)