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Analysis of Meteorological Factors Influencing Soybean Yield in Keshan County and Research on Meteorological Model of Yield

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ABSTRACT. *The influence of meteorological factors on soybean yield during different growth periods was revealed by using correlation analysis based on soybean yield and daily meteorological data during the growth period in Keshan County, Heilongjiang Province from 1986 to 2015. The results showed that the average temperature, rainfall and sunshine hours of each month during soybean growth period from 1986 to 2015 showed upside-down trend, and the minimum and maximum values all appeared in different months; the hours of sunshine in June and August, namely light of the flower bud differentiation stage and pod setting stage in soybean growth period, its negative effects on soybean yield reached extremely significant levels ($p<0.01$) and significant levels ($p <0.05$), respectively. And the moving average simulation method and multiple linear regression method were used to separate the actual soybean yield into trend yield and meteorological yield; the meteorological yield prediction model was established in according with temperature, rainfall, sunshine hours and other meteorological factors, the results showed that the rainfall had a greater impact and it was positive, the next were average temperature and sunshine hours, both of which were negative effect. Finally, the prediction accuracy of the meteorological yield prediction model was analyzed.*

KEYWORDS: *yield; meteorological factor; meteorological yield model.*

1. Introduction

The soybean acreage in Heilongjiang Province has reached one third of the country, and the annual yield accounts for about 40% of the total yield of the country, climate change have a significant impact on soybean growth and development and yield formation. Deeply understanding the response of soybean production to meteorological factors is of great significance for accurately assessing fluctuation of soybean production under the background of climate change, moreover, it is of practical significance for guiding farmers' soybean planting

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management [1-3]. This paper took Keshan County as a research area, through analysis of the meteorological factors affecting soybean yield, the influence of climate resource changes on soybean growth and development was explored, the meteorological model that affects soybean yield factors was established, this provides references for making full and reasonable use of climate resources and predicting soybean yield.

2. Materials and Methods

2.1 Data sources

The soybean acreage, yield data, and meteorological data of Keshan County from 1986 to 2015 were used, originated in came from China meteorological data sharing service system and statistical yearbook, respectively.

2.2 Data processing and analysis

The meteorological yield can be expressed by the formula $y_w = y - \hat{y}_t - e$, yw is meteorological yield, y is the actual yield, $\hat{y}_t$ is the trend yield, and e is the yield affected by random factors. The moving average simulation method was used to remove the short-term fluctuations of production caused by meteorological factors, and find the trend yield to obtain the meteorological yield [2].

The data were analyzed by EXCEL analysis and SPSS software.

3. Establishment and Analysis of Soybean Trend Yield Model

3.1 Descriptive statistical analysis of meteorological factors

The soybean varieties commonly planted in Keshan County, Heilongjiang Province are Keshan No.1, Heisheng, Kedou, etc. their growth period was from May to September every year, the average temperature, rainfall and sunshine hours during the soybean growth period from 1986 to 2015 were calculated and analyzed, as shown in Table.1.

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Table 1 Analysis of meteorological factors in Keshan County, Heilongjiang Province from 1986 to 2015

project		May	June	July	August	September
average temperature/°C	average	13.8	20.2	22.1	20.2	13.5
	maximum	34.8	38.7	37.1	33.4	33.4
	minimum	-4.7	1.5	8.4	4.5	-3.4
	range	39.5	37.2	28.7	28.9	36.8
	relative range	2.86	1.84	1.29	1.43	2.73
	standard deviation	4.98	4.98	4.96	4.97	4.99
	coefficient of variation /%	36	25	22	25	36
rainfall/mm	average	1.2	2.8	5.5	3.5	1.8
	maximum	33.7	100.9	100.2	62.9	54.5
	minimum	0.0	0.0	0.0	0.0	0.0
	range	33.7	100.9	100.2	62.9	54.5
	relative range	28.08	36.04	18.22	17.97	30.28
	standard deviation	7.95	7.95	7.95	7.94	7.95
	coefficient of variation /%	663	284	145	227	442
sunshine hour /h	average	8.3	8.7	7.7	7.8	7.8
	maximum	14.8	15.1	15.2	14.3	12.9
	minimum	0.0	0.0	0.0	0.0	0.0
	range	14.8	15.1	15.2	14.3	12.9
	relative range	1.78	1.74	1.95	1.81	1.65
	standard deviation	4.43	4.43	4.43	4.45	4.45
	coefficient of variation /%	53	51	57	56	57

3.1.1 Temperature

During the months of soybean growth period, the average temperature presents upside-down trend, its lowest value appeared in September and its highest value appeared in July, the coefficient of variation of average temperature of each month was just opposite to the temperature change, it showed upside-down trend, the coefficient of variation in July was the lowest, and the coefficient of variation in May was the same as September and highest, the relative range was used to express the discrete degree, the relative range was between 1.29 and 2.86, It can be seen that the temperature changed greatly in May, it had a great impact on germination and emergence of soybean, the temperature was relatively stable in July and August, which was conducive to soybean flowering and pod setting and promoted soybean irrigation.

3.1.2 Rainfall

During the months of soybean growth period, the average monthly rainfall was the same as the average temperature, all were upside-down trend, its lowest value

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appeared in May and its highest value appeared in July, the coefficient of variation of average rainfall of each month was relatively large, which was between 145% and 663%, its maximum coefficient of variation appeared in May and the minimum coefficient of variation appeared in July; the relative range of the average rainfall was between 17.97 and 36.04, the minimum was in August, and the maximum was in June, it showed that the rainfall was relatively concentrated in June, but it was scattered in August, soybean in June was in the period of flower bud differentiation, flower bud differentiated, and plants entered into period of reproductive growth and vegetative growth at the same time, at this time, effective rainfall was beneficial to flower bud differentiation of soybean.

3.1.3 Sunshine hours

During the months of soybean growth period, the average sunshine hours presented upside-down trend, its highest value appeared in June and its lowest value appeared in July; the coefficient of variation was between 51% and 57%, the maximum appeared in July and September, and the minimum appeared in June; the relative range was between 1.74 and 1.95. In summary, the flowering and pod setting period was the most vigorous period of soybean growth period, it was the period that requires the most water and nutrients, and it also needs enough light, which plays an important role in improving the quality of soybean seeds.

3.2 Correlation analysis of meteorological factors

The correlation analysis of the average temperature, rainfall, and sunshine hours three meteorological factors, and meteorological factors and actual yield (per unit yield) during the soybean growth period from 1986 to 2015 is shown in Table 2.

Table 2 Correlation analysis between climate factors and yield in Keshan County, Heilongjiang Province from 1986 to 2015

project	May	June	July	August	September
average temperature-rainfall	-0.182**	-0.249**	-0.219**	-0.088**	-0.041
average temperature-sunshine hours	0.303**	0.431**	0.436**	0.167**	0.201**
rainfall-sunshine hours	-0.404**	-0.385**	-0.435**	-0.421**	-0.429**
average temperature-actual per unit yield	0.232	-0.248	0.036	-0.269	-0.109
rainfall-actual per unit yield	0.049	0.222	0.210	0.248	0.248
sunshine hours-actual per unit yield	-0.028	-0.475*	-0.329	-0.472*	-0.082

Note: * is significant correlation at the 0.05 level (both sides); ** is significant correlation at the 0.01 level (both sides).

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3.2.1 Correlation among indexes

The average temperature presented negative correlation with the rainfall during each growth period, it showed that during the soybean growth period, when the rainfall increased, the average temperature decreased, and the rest of the months presented extremely significant negative correlation except September ($p < 0.01$); the average temperature presented positive correlation with the sunshine hours during each growth period, it showed that as the average temperature increased, the average sunshine hours also increased, and there was significant correlation among each month during the growth period ($p < 0.01$); the rainfall presented extremely significant negative correlation with the sunshine hours in each month of the growth period ($p < 0.01$), it showed that in the months with more rainfall, the average sunshine hours decreased significantly.

3.2.2 Correlation between indexes and actual yield

There was no significant correlation between the rainfall and the actual yield during the sowing and germination period (May), however, the average temperature presented extremely significant negative correlation with rainfall ($p<0.01$), it showed that the rainfall increased during this period, and the average temperature dropped accordingly, proper rainfall can promote the growth of seedlings, flood and drought all cause soybean yield to be lost; the hours sunshine presented significant negative correlation with the actual yield during flower bud differentiation period(June) ($p<0.05$), while the sunshine hours presented extremely significant positive correlation with the average temperature ($p < 0.01$), it showed that at this stage, the increase of sunshine hours and temperature was conducive to the differentiation of soybean flower buds, thus reaching the requirements of strong plants, many branches, many flower buds and healthy flowers; the sunshine hours presented significant negative correlation with the actual yield during the pod setting period (August), ($p<0.05$), and the sunshine hours presented extremely significant positive correlation with the average temperature($p<0.01$), and soybean is crop which like warm, this stage showed that the increase of sunshine hours caused the temperature to rise, and accumulated temperature rose, the average temperature in August was 20.2°C, the optimal temperature for soybean pod setting and grain filling period was between 21-23°C, so it was conducive to of soybean pod setting, soybean grain fullness was guaranteed; the correlation between meteorological factors and actual yield during other growth periods was not obvious.

3.3 Establishment of trend yield model

The time dynamic model is an ideal yield prediction model; this prediction model theoretically believes that the process of grain production is comprehensively influenced by the productivity level of natural factors. Through the statistics of 30 samples from 1986-2015 in Keshan County, Heilongjiang Province, the 5-year per unit yield was used to carry out smooth simulation to analyze the impact of

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meteorological factors on the actual yield of soybeans, so as to reflect the contribution to soybean yield due to historical development and technological upgrading, The average yield of 5-year actual per unit yield as the trend per unit yield in one year:

$$\hat{y}_t = \frac{\sum_{i=t-2}^{t+2} y_i}{5} = \frac{1}{5}(y_{t-2} + y_{t-1} + y_t + y_{t+1} + y_{t+2})$$

y_t express the actual per unit yield in the t-year, and $\hat{y}_t$ express the trend yield in the t-year. The trend yield is the yield corresponding to the total trend curve of soybean yield per year, which is different from the actual yield, its difference can be considered as the result of meteorological factors, and therefore, the meteorological yield can be positive value or negative value. If the meteorological yield in t year is positive, it means that compared with the average year, the meteorological conditions in that year are conducive to the production increase; on the contrary, the meteorological conditions in that year are not conducive to the production increase.

As can be seen from Fig.1, meteorological conditions in 1988, 1991, 1993, 1994, 1996, 1997, 1999, 2002, 2005, 2006, 2008, 2009, 2010, 2013, 2015 are more conducive to the increase of soybean production, and other years are not conducive to the increase of soybean production.

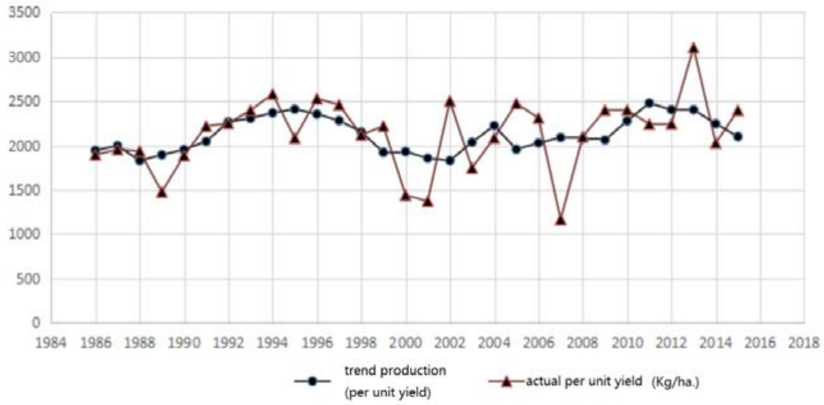

Fig. 1 comparison diagram of actual per unit yield and trend per unit yield of soybean in Keshan County, Heilongjiang Province from1986 to 2015

4. Establishment of Soybean Meteorological Yield Model

Meteorological yield is the soybean yield influenced by meteorological factors, which can be expressed by the formula $y_w = y - \hat{y}_t - e$, y_w is meteorological

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yield, y is the actual yield, $\hat{y}_t$ is the trend yield, and e is the yield affected by random factors. Meteorological yield is mainly determined by temperature, rainfall, sunshine hours, etc, the meteorological yield model is established with multiple linear regression analysis methods in according with the correlation between meteorological factors during the growing period. The specific model is as follows:

$$y_m = \alpha t + \beta r + \gamma s + \mu$$

$$y_w = S * y_m$$

y_m is the simulateion value of soybean per unit yield, y_m is the meteorological yield of soybean, S is the soybean acreage in that year, t is the monthly average temperature, r is the monthly average rainfall, s is the monthly average sunshine hours, and μ is the error. α, β, γ are the coefficients of temperature, rainfall and sunshine hours, respectively [2].

Through the multiple linear regression analysis of meteorological factors and meteorological yield in Keshan County, Heilongjiang Province from 1986 to 2015, the meteorological model of yield is established as follows:

$$y_w = (-24.860t + 45.877r - 212.946s + 4172.456) * S$$

The coefficients in the model showed that rainfall was the main influencing factor of meteorological yield, its role was positive, the next were average temperature and sunshine hours, both of which are negative.

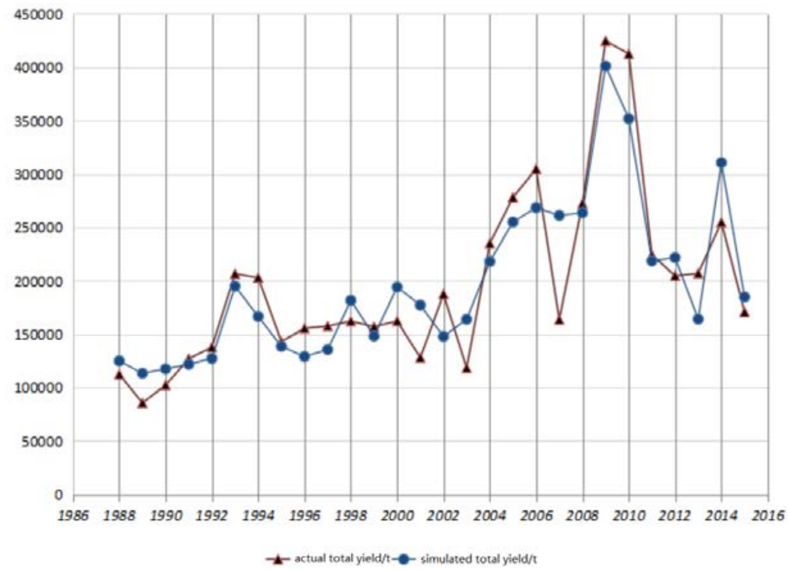

Fig. 2 comparison diagram of actual total yield and simulated total yield of soybean in Keshan County, Heilongjiang Province from 1986 to 2015

The meteorological yield model was used to compare simulated soybean yield and actual soybean yield (as shown in Fig.2), 1991, 1992, 1993, 1995, 1999, 2004, 2005, 2008, 2009, 2011, 2012 and 2015, the actual total yield are 127033, 137774, 206598, 143017, 156967, 234950, 278042, 272219, 424572, 224190, 204695 and 170837 tons, respectively, and the simulated total yield are 121924, 127271, 194855, 138566, 148264, 217927, 255054, 263697, 400967, 218499, 221667 and 184762 tons, respectively, the fitting effect is better; the simulation effect in a few years is slightly worse. R2 diagram of simulated soybean yield and actual soybean yield is obtained by observing multiple linear regression (Fig,3), coefficient of determination is $R^2 = 0.8252$, it shows that the effect of the regression model is better.

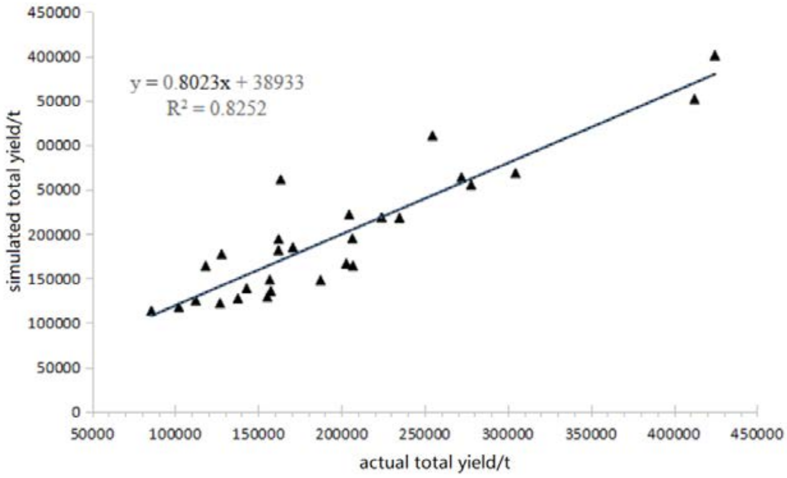

Fig. 3 R^2 diagram of actual yield and simulated yield of soybean

5. Conclusion and Discussion

Change of meteorological factors brings complicated impacts on soybean yield, large temperature fluctuations, uneven rainfall distribution, and decrease of sunshine hours are all important factors affecting high yield of soybean. Through studies and analysis of the average temperature, rainfall, sunshine hours and change of agricultural climate resources during the soybean growth period from 1986 to 2015 in Keshan County, Heilongjiang Province, this paper draws relevant conclusion: the influence and effect of meteorological factors at different development stages on soybean yield are different, rainfall at the seeding and germination stage is an important factor affecting soybean yield, flood or drought during this period may cause soybean yield to be lost; the average temperature during flowering and pod setting stage is an important factor affecting soybean yield, if low temperature occurs during this period, it also lead to cut in soybean production; and the pod setting and grain filling period is an important stage of the yield formation of soybean, during this period, the sunshine hours have great impact on the soybean yield. The rise of average temperature can lead to increase of sunshine hours, pod setting and grain filling receive enough light, which cause soybean to increase yield.

According to temperature, rainfall, sunshine hours and other meteorological factors, the trend yield was calculated with the yield moving average, and the prediction model of meteorological yield was established, the results showed that the rainfall had a large impact and positive effect, the next were the average temperature and sunshine hours, both of which were negative effect. This model only preliminarily calculates the soybean yield and the rainfall, average temperature and sunshine hours during the growth period, the influence of biological factors (such as pests and diseases) on soybean yield had not been calculated, therefore, this model still has a lot of limitations, and related problems need to be further studied.

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