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The Effects of Weather on Oilseed Rape (OSR) Yield in China: Future Implications of Climate Change

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Abstract: Understanding the role of climatic factors on crop yields is essential in predicting the future impact of climate change. In order to understand the influence of climatic factors on OSR, detailed farm-level panel data from 2566 farms across 67 counties of the 6 major OSR production regions in China, from the surveys conducted by the national OSR industry project between 2008 and 2013, were used to examine the contribution of changes in selected climatic variables between 2008 and 2013 to yield variation. Spatial and temporal patterns of the relationships between OSR yield, climatic factors were estimated together with the effects of farmer adaptation and management practices on yield variability. The analysis revealed that yields in the low-latitude production regions were more sensitive to temperature increases and likely to decline. Precipitation iwas the most influential factor on yield at the first two growth stages; temperature and sunshine hours were most important at the third and fourth growth stages, respectively. Labour input was the most influential management factor affecting yields compared with fertilizer and other inputs. The study concludes that projection of future climate change impacts will need inter alia to incorporate more sophisticated and detailed measures of climatic variables than simple means of temperature and precipitation, incorporating timing in relation to plant growth and yield.

Keywords: OSR yield; climate and management factors; spatial and temporal impact; China

1. Introduction

Past and projected future climate change impacts on crop yields have received a great deal of attention by the international scientific community. Most studies have focused on wheat, rice, maize or soybean (Ray et al. [1], Scealy et al. [2], Butler et al. [3], Asseng et al. [4]). The correlation between yield and specific climatic variables differ spatially for different crops. They are also region specific given the differing regional management practices, soil types, duration and timing of crop exposure to climatic conditions (Porter et al. [5]). Lobell et al. [6] estimated that over the period 1980–2008, global temperature and precipitation trend impacts accounted for a 3.8% decrease in maize yields, a 0.1% decrease in rice yields, a 5.5% decrease in wheat yields and a 1.7% decrease in soybean yield. At the country scale, the impact of climate change on crop yield exhibits wide variation. For example, climate impacts accounted for a large part of yield gains for maize in China and wheat in Russia, Turkey, and Mexico (Easterling et al. [7]). Even within a country, the impact may vary across regions. Rice yields in China have been found to be positively related with temperature in some regions and negatively related in others (Zhang et al. [8,9]). According to the fourth assessment report of the IPCC (IPCC [10]), crop yields in low-latitude regions are more likely to decrease under even slight warming.

How changes in climatic variables can affect OSR yields has received less attention. A study considered how variations in climate factors affect the growth period and yield of OSR through crop simulation models such as APSIM-canola (Wang et al. [11]). Other studies have focused on how climate change can affect OSR plant disease incidence from an agronomic perspective (Evan et al. [12], Eickermann et al. [13]). Few studies have been conducted in which the impact of management and climate are both included in examining the variability of yields from economic perspectives, given that both can vary inter-temporally and inter-regionally.

OSR (rapeseed, canola) is grown throughout the world as a source of cooking oil, animal feed protein and for fuel as a component of bio-diesel. It was the third most important source of vegetable oil and the second most important source of protein meal worldwide in 2015 (USDA [14]). Global production of OSR from 2000 to 2013 increased at an average annual growth rate of 2.5%. The four largest producers are the European Union (EU), Canada, China and India, accounting for 28%, 25%, 20% and 11%, respectively, of global OSR production in 2013 (FAOSTAT [15]). Changes in OSR production in China, as the world's third largest producer and biggest importer since 2012, can have a profound influence on the world OSR market (see Table 1).

Table 1. OSR imports by the four largest importing countries: 2012 to 2015.

Country	2012	2013	2014	2015
	million tonnes			
China	3.42	5.05	4.50	3.30
EU	3.38	3.50	2.30	2.20
Japan	2.50	2.38	2.45	2.45
Mexico	1.38	1.49	1.54	1.50

Sources: United States Department of Agriculture (USDA [14]).

Yield fluctuations are an important contributor to variation in China's OSR production and import levels. From 2000 to 2014, the mean absolute percentage deviation (MAPD) from trend of area planted was 2.7 compared with 3.3 for yield, and since 2009, yield MAPD rose to 3.4, whilst that of area planted fell to 1.0, suggesting yield has been a greater contributor to production variability in China in more recent years.

China's climate has already warmed by more than the global mean temperature rise over the past century. Hence, an understanding of the effects of annual variations in key climate parameters on China's OSR yields can contribute to gauging the potential influence of future long-term climate change on production, and also to what might be the mitigation potentials from adaptation and adjustment of management and economic inputs.

The focus of the study therefore is to analyze the spatial and temporal pattern of the impact of climate variables on Chinese OSR yields, namely the relative susceptibility of major OSR producing regions to particular climatic variables, and to determine at which growth stages specific climate variables exert more influences on yields. Moreover, identifying the particular regions and growth stages of OSR that have been most affected by variability in climatic indicators could assist efforts to measure and analyze ongoing efforts to adapt and to quantify the extent to which economic inputs might mitigate some of the impact of climate variability. Given assumptions about future changes in key climatic variables in the estimated model, locational changes in future yields and production can also be projected. We are aware that it needs data from a long time period to conduct a climatic analysis. However, future implications of climate change from data analysis based on a limited number of consecutive years, which contain some variation in climate, can also be useful in providing insights into its effects. The data used were obtained from farm surveys conducted annually by the national OSR over the period 2008–2013.

Translating climate variations into potential yield impacts requires a yield response model. Regression analyses of historical data have commonly been employed to relate yields to climate, notably to mean annual temperature and/or precipitation (Ray et al. [1], Lobell et al. [6])

Some authors have added a trend term as a proxy for the effect of other factors such as productivity gains and technological change. In such studies, the impact of climate is seen as contributing to the yield variation around the trend. In other studies, physical inputs such as labour, fertilizer, pesticide and seeds, etc. have been explicitly included as explanatory variables (You et al. [16]). The farm-level survey data employed for the yield modelling in this paper include physical and economic inputs in OSR production, as capturing farmers' adaptation can help to understand the role of climate relative to non-climate factors in yield variations.

As for the specification of yield-climate models in the literature, both linear and quadratic forms of climate variables have been used in previous studies (Ray et al. [1], He et al. [17], Lobell et al. [6], Rowhani et al. [18], You et al. [16]). We explored a range of statistical models including log linear, quadratic log and translog specifications relating observed variations in temperature, precipitation and sunshine hours during the OSR growing season to the observed variations in yield in each production region. The 'best-fit' model for all of the regions was then selected

The remaining sections of the paper are organized as follows. Section 2 outlines OSR production developments in China, and the climate characteristics of major OSR production regions in China. A brief description of the theoretical framework and model specifications are given in Section 3. Section 4 is the data description. The estimation results and discussion are presented in Sections 5 and 6, respectively, and Section 7 concludes.

2. OSR Production in China

2.1. Recent Developments in OSR Production

In China, OSR is the most widely grown of the various major oilseed crops which also include soybeans, peanuts, sunflowers and sesame. Indigenous soybeans are mainly used for edible soybean products like soybean curd and soya milk etc., whilst imported soybeans are permitted only for use in the production of soy oil and animal feeds according to governmental rules (Zhu et al. [19]). The sown area of OSR accounted for 53.7% of the total oilseed crop sown area, and OSR production for 41.1% of oilseed crop production in 2013 (National Statistics Bureau of China [20]). Nevertheless, the annual average growth rate in Chinese OSR production at 1.9% lagged behind the global mean rate over the period 2000 to 2013. Growth in average yields increased at a rate of 1.8%, implying a relatively static rate of growth in planted area, with yield the primary driver of output growth. Meanwhile, domestic consumption of OSR exhibited an average growth rate of 2.8% per year from 2000 to 2013, driven primarily by the demand for animal feed as domestic demand for meat and milk expanded.

2.2. Climatic Characteristics of Each OSR Production Region in China

The majority of OSR production in China is winter OSR, accounting for about 90 percent of output. It is grown throughout most of central, eastern and southern China, while spring OSR is grown in northern China. The fourteen major winter OSR production provinces have been aggregated into 7 geographic regions by Zhang et al. [21] (see Table 2). The harvested OSR area, yield and production of each region are also shown in Table 2.

Each production region of winter OSR has its own climatic characteristics. Region I (Southern China) is a tropical and subtropical area which is warm through the whole year and has high humidity. Winter is shorter and warmer in this region than in other regions. However, OSR in this region is more likely to suffer from plant diseases and insect pests. Region II (Huang-Huai plain) has cold and dry winters. Drought occurs frequently in spring. Region III and Region IV (Yunnan-Guizhou plateau and Sichuan basin) have warm and dry winters. Especially in Region IV (Sichuan basin), a cold wave is less likely to affect this region. However, sunshine hours are generally fewer than in other regions.

Regions V and VI (middle reaches of Yangtze river, lower reaches of Yangtze river) are subtropical areas. Region V has rainy springs and summers, and dry autumns and winters. Frost damage in winter occurs frequently (Liu et al. [22]).

Table 2. Winter OSR harvested area, yield and production of each region in 2013.

Region	Region Name	Provinces Included	Harvested Area (1000 ha)	Yield (kg/ha)	Production (1000 Tonnes)
I	Southern China	Guangxi	18.8 (0.3)	1012.9	19.0 (0.1)
II	Huang-Huai Plain	Anhui, Henan	939.5 (13.6)	2353.8	2198.5 (16.7)
III	Yunnan-Guizhou Plateau	Yunnan, Guizhou	801.7 (11.6)	1666.2	1324.6 (10.0)
IV	Sichuan Basin	Sichuan, Chongqing	1213.6 (17.6)	2052.5	2641.4 (20.0)
V	Middle Yangtze River	Hubei, Hunan, Jiangxi	3034.2 (44.0)	1624.1	5155.1 (39.1)
VI	Lower Yangtze River	Jiangsu, Zhejiang, Shanghai	579.5 (8.5)	2287.5	1462.1 (11.1)
VII	Loess Plateau	Shaanxi	306.6 (4.4)	1940.4	396.7 (3.0)
ALL	–	–	6893.9	1937.9	13,197.5

Note: The figures in parentheses are the respective regional percentage shares of total area and total production in the seven regions (National Statistics Bureau of China [20]).

2.3. Climate and Its Variation in Relation to OSR Production in China

Many of the growth stages of OSR overlap during the life cycle of the plant. A standardized growth stage scale developed by BASF, Bayer, Ciba-Geigy and Hoechst called the BBCH decimal system provides an accurate and simplified approach to illustrate growth stages of OSR and is shown in Table 3. The influence of climate variables on OSR growth varies from one stage to another. In order to specify the influence of climate variables for the different stages of OSR growth, four main growth stages were used (see Table 3). From an agronomic perspective, accumulated growth degree days (AGDD) (Accumulated Growing Degree Days measure heat accumulated by a crop over a period of n days and is given by AGDD $= \sum_{t=1}^{n} DGDD_t$, $t = 1...n$, where a daily growing degree day (DGDD) is obtained as: DGDD $= (MaxT + MinT)/2 - BaseT$, where $MaxT$ is the highest temperature of the day and $MinT$ is the lowest temperature of the day. $BaseT$ represents the temperature below which no development occurs for OSR. 0 °C was chosen as a base temperature for OSR in the study. DGDD represents the daily heat useful for OSR growth. Values of DGDD greater than zero are added summed as the accumulated growing degree days for each growth stage), accumulated precipitation (AP) and accumulated sunshine hours (ASH) are the most important factors influencing crop growth (Liu et al. [23]). The analysis therefore incorporated values for AGDD, AP and ASH for each of the four growth stages and for each region.

Table 3. Classification of growth stages of OSR (Canada Canola Council [24]).

Growth Stages	Stages Used in the Study
Stage 0 Pre-emergence Stage 1 Seedling emergence	Stage 1
Stage 2 Stem elongation (“rosette”) Stage 3 Flower bud development	Stage 2
Stage 4 Flowering	Stage 3
Stage 5 Ripening	Stage 4

Over the past 50 years, the yearly average temperature of China has increased by 1.1 °C. Annual average precipitation has also increased over this period, notably in the middle and lower reaches of Yangtze River, which are the major OSR production regions, where it rose from 60 to 130 mm per year. Conversely, annual average sunshine hours fell by 130 h (5%). The dramatic increases of greenhouse gasses and aerosols are believed to be the main reasons for these changes (Ding et al. [25]). Table 4 shows the mean AGDD, AP and ASH and their respective coefficients of variation (CV) over the entire OSR seasonal growth period in each region (In the study, climate data were obtained from the China Meteorological Data Sharing Service System).

Table 4. Regional climatic variation over the period 2008–2013.

Region Climate Variables	I	II	III	IV	V	VI	VII
AGDD (°C)	2858	2493	2750	2850	2530	3012	3131
CV	0.1	0.0	0.0	0.0	0.0	0.0	0.0
AP (mm)	437	364	268	292	577	582	393
CV	0.14	0.28	0.21	0.15	0.19	0.24	0.23
ASH (hours)	538	1073	858	453	996	1094	965
CV	0.20	0.14	0.06	0.15	0.15	0.09	0.14

Source: China Meteorological Data Sharing Service System [26]. Data here were calculated by the author.

3. Theoretical Framework and Model Specification

We hypothesize that the observed OSR yield in a given region is a function of physical and financial inputs, land quality, technology, management, and climate factors of the general form in Equation (1).

$$Y = f(L, K, C, t) \tag{1}$$

in which Y denotes yield. L is a vector of labour inputs, K is a vector of capital inputs, C is a vector of climate factors and t denotes a time trend reflecting technological progress.

As yields and the explanatory variables follow a log-normal distribution, we specify Equation (1) with all variables in natural logarithms as in Equation (2), which can be estimated by OLS.

$$LnY = \alpha_0 + \alpha_1 t + \beta_1 LnL + \beta_2 LnK + \beta_3 LnC \tag{2}$$

in which, α_1 is the trend yield annual growth rate and β_j are vectors of yield response elasticities.

Given that farm-level survey data are available to estimate the yield model, the possibility of including physical, economic and management inputs in OSR production into the model can help to capture farmers' short run adaptation to climatic variation and hence explain the relative importance of climatic variation with respect to yield. Explaining yield changes in terms only of climatic variation may mis-specify the determinants of observed yields and their temporal and spatial differences (This is in contrast to experimental data measuring yield response to a single variable where all other variables can be controlled). Reference was made in Section 1 to studies which employed both log linear and quadratic log forms of models. We tried to choose one 'best fit' model form from log linear, quadratic log and translog forms for all the regions. However, because the study is multi-regional, and recognizing the fact that different functional forms have the best fit in different regions, together with the fact that more complex functional forms would reduce the available degrees of freedom in regions where sample size was relatively small (viz. region I), in the interests of parsimony and to ensure comparability of interpretation, a common equation specification was imposed and is as follows:

$$Lny_{rit} = (\alpha_0 + \alpha_t t) + \sum_{h=1}^{4} w_{rh} LnC_{rhit} + \sum_{k=1}^{3} \beta_{rk} Lnx_{rkit} + \sum_{m}^{5} \delta_{rm} z_{rmit} + \gamma_r D_r + \mu_{rit} \tag{3}$$

where Ln is natural log, $t = 1, 2, \ldots, 6$ is a time variable representing survey year (t(2008) = 1), y_{rit} is OSR yield for farm i at time t in region r (a time trend from 2008 to 2013). C_{rhit} represents climate variables in growth stage h of OSR grown by farmer i at time t in region r, including AGDD, AP and ASH. x represents the physical inputs per hectare of OSR including labour (l), chemical fertilizer (f), and other inputs (om) such as seeds, pesticide, machinery, agricultural plastic film and irrigation. z represents other socio-economic factors which may influence yield. D is a dummy variable representing farmer's social status as to whether the farmer occupied any administrative position in the village. The parameters $\alpha, w, \beta, \delta, \gamma$ are to be estimated and μ is the error term.

4. Data

The panel data used were obtained from farm surveys conducted annually by the national OSR industry project with 3743 winter OSR producing farms from 136 counties in 14 major winter OSR production provinces over the period 2008–2013. The data from region VII (Loess Plateau sub-region) were not used due to the small sample size. Hence, observations from 2566 farms across 67 counties have been used in the study. The sample size in each region is shown in Table 5. The survey covered information on farmer characteristics, sown areas of OSR, inputs and outputs of OSR production, etc.

Table 5. The number of farms in the survey in each region each year.

Region	The Number of Counties	The Number of Farms
I Southern China	5	111
II Huang-Huai Plain	13	302
III Yunnan-Guizhou Plateau	12	370
IV Sichuan Basin	8	345
V Middle Yangtze	21	1126
VI Lower Yangtze	8	312
VII Loess Plateau	5	94

Source: Survey data from 2008 to 2013.

The sowing period of OSR varies from one province to another depending on the climatic conditions. OSR is sown later in lower latitude areas compared with those at higher latitudes. Since the sowing and harvest dates may have varied in the last six years due to climatic as well as technological and socio-economic changes in each region, ideally the sowing and harvesting dates should be given as a function of time. However, the survey dataset did not record OSR sowing and harvest dates for each farm, which would in any case exhibit some intra-regional variability according to the prevailing weather conditions. Thus, fixed OSR sowing and harvested dates in each region were specified, as in other studies (Ray et al. [1]). Winter OSR is generally sown in September or October and harvested in April or May in China, and the specific growth stage dates for each province are shown in Appendix Table A1. It was assumed that OSR growth periods within a province were identical. The AGDD, AP and ASH of the four main growth stages of OSR were derived from county climate records. Farmers living within a county were assumed to grow OSR under the same weather conditions.

Non-climate inputs include labour (l), chemical fertilizers (f) and other physical inputs (om) such as seeds, pesticides, machinery, agricultural plastic film and irrigation. Labour inputs were measured in terms of working days per hectare, physical inputs as expenditure (in RMB per hectare) deflated by the annual price indices of the means of agricultural production (AMPI) from the China Statistical Yearbook (National Statistics Bureau of China [20])published by the National Bureau of Statistics of China (2008 = 100). Chemical fertilizer was included individually, whilst seeds, pesticide, machinery, agricultural plastic film and irrigation inputs were combined into an aggregated category of "other inputs".

A set of variables representing farmers' socio-economic characteristics and management skills were also included. The latter comprised human capital elements including farmer's age (a proxy for experience), educational level (technological awareness and competence), the degree of OSR specialization on the farm (farmer knowledge), agricultural income per hectare (competence in farming), agricultural skills training frequency, and the farmer's social status as to whether he/she is a local village administrator. The age of farmers was included in the model, as older farmers may be more experienced in OSR production, although on the other hand they may have less energy and hence contribute less labour to OSR production. The influence is a priori uncertain. The annual agricultural skill training a farmer undertook was a proxy element of human capital in addition to level of education. Whether the farmer occupied any administrative position in the village represented his/her social capital and was represented by a dummy variable. Farmers who are more capable are more likely to be selected to work in administration. They may also have more access to marketing information, new agricultural technologies, etc. However, farmers with administrative positions also tend to spend less time farming. Hence, a priori the impact of farmers' social status on yield is uncertain (Whilst it may be also correlated with farmers' educational level, the test for correlation was non-significant). The production specialization of farmers is represented by the share of the OSR area relative to a farmer's total farming area and agricultural income per hectare. It is anticipated that farmers with a higher proportion of their land allocated to OSR have more suitable land and more experience in OSR production, whilst recognizing that within limits, it may reduce rotational opportunities which could have negative impacts on OSR yield.

An overview of data used for the regression analysis is summarised in Appendix Table A2, and regional mean values for all survey variables used in the study are given in Appendix Table A3.

5. Estimation and Results

As a first step in the analysis, the correlation matrix of variables was examined in order to pre-test for possible collinearity. Survey sample cases containing outliers in the dependent or explanatory variables were also removed. Hausman and likelihood ratio tests indicated a fixed-effects model was the most appropriate specification. These were estimated by Ordinary Least Square regression (OLS) (Estimation was by EVIEWS 6.0 (IHS Global Inc.: Irvine, CA, USA, 2008)) with the results for each region shown in Table 6. The models are statistically significant according to the Prob-value from the F-statistic. The estimated coefficients of climatic variables and physical variables are interpreted as elasticities (e.g., the coefficient for labour input in region I of 0.15, means a 1% increase in labour input would lead to a 0.15 percent increase in OSR yield).

Table 6. Fixed effect estimates of determinants of OSR yield.

Explanatory Variable	**I**	**II**	**III**	**IV**	**V**	**VI**
Ln(AGDD1)	3.91	−0.96 **	0.30	0.06	0.11	0.42
Ln(AP1)	1.23 **	0.25 ***	0.08 *	−0.01	0.04 ***	−0.28 **
Ln(ASH1)	5.39 ***	−0.03	−0.04	−0.04	0.10 **	−0.90 **
Ln(AGDD2)	−0.35	0.22	−0.07	0.01	−0.03	0.73 ***
Ln(AP2)	1.37 **	0.13 ***	0.07 **	−0.01	0.01	−0.01
Ln(ASH2)	3.65 **	−0.02	0.05	−0.01	−0.01	0.14
Ln(AGDD3)	−5.52 **	0.55 **	−0.11	0.13	0.05	−1.12 *
Ln(AP3)	−1.99 ***	0.02	0.00	0.00	0.02	−0.05
Ln(ASH3)	−0.38	−0.27	0.09	−0.03	0.02	0.09
Ln(AGDD4)	−18.79 **	0.97 **	−0.32	−0.53	−0.21 *	0.59
Ln(AP4)	0.92 **	0.00	0.04	0.02	−0.01	−0.09 **
Ln(ASH4)	10.82 ***	0.52 **	0.12	0.12	0.10 **	−0.52 ***
constant	29.46 *	0.26	6.85 **	9.50 ***	6.16 ***	11.95 ***
time	1.19 ***	−0.06 ***	−0.01	0.02	0.02 ***	0.00
Ln(*l*)	0.15 ***	0.11 ***	0.05	0.10 ***	0.08 ***	0.15 ***
Ln(*f*)	−0.05 ***	0.03 *	0.00	0.01	0.02 ***	0.01
Ln(*om*)	0.02	−0.01	0.01	0.02 *	0.02 ***	0.01
Age	−0.02 *	0.00	0.00	−0.00	−0.00	0.01
Education	0.06 **	0.01	−0.01	−0.01	0.01	−0.01
Training	−0.04 *	−0.00	0.03 ***	0.00	0.02 ***	−0.01
Social status	0.05	−0.08	0.09	−0.04	−0.00	0.01
Rapeseed area%	−0.71 ***	−0.69 ***	−0.54 ***	−0.53 ***	−0.23 ***	−0.22 ***
Agr. income	0.00 ***	0.00 ***	0.00	0.00 ***	0.00 ***	0.00
Adjusted R^2	0.55	0.40	0.66	0.58	0.54	0.63
Prob(F-statistic)	0.00	0.00	0.00	0.00	0.00	0.00

Notes: *, ** and *** represent 0.10, 0.05 and 0.01 levels of statistical significance, respectively.

6. Discussion

6.1. Spatial Pattern of Impact of Climate Variables

The coefficients reflect the proportional yield change when the level of each climate variable changes by 1 percent. It is, however, perhaps more meaningful to consider changes in the levels of each climate variable. For example, in Region I at growth stage 1, the mean AP is 554.5 mm. Hence, a 10 mm increase in the average AP during the second growing period (i.e., 1.8 percent increase in the average AP) would generate an increase in OSR yield of 2.2% (A 10 mm increase in the average AP in Region I at growth stage 1 equals to 1.8% increase, i.e., $\left(\frac{10}{554.5}\right) \times 100\%$. Since a 1% increase in the average AP at growth stage 1 generates 1.2% increase in OSR yield (see Table 6), a 1.8% increase in the average AP would generate 2.2% increase in OSR yield, i.e., 1.8 × 1.2%. That means a 10 mm increase in the average AP generates 2.2% increase in OSR yield). The corresponding impacts in each growing period in each region of a 10 mm rise in AP, a 1 °C increase in AGDD and 1 h increase in ASH are shown in Table 7.

Table 7. The impact of a 10 mm rise in AP, a 1 °C increase in AGDD and 1 h increase in ASH on yield.

Region Climate Variables	**I**	**II**	**III**	**IV**	**V**	**VI**
Ln(AGDD1)	–	−0.09 **	–	–	–	–
Ln(AP1)	2.22 **	1.67 ***	0.25 *	–	0.13 ***	−0.95 **
Ln(ASH1)	1.41 ***	–	–	–	0.03 **	−0.20 **
Ln(AGDD2)	–	–	–	–	–	0.10 ***
Ln(AP2)	10.80 **	0.84 **	0.33 **	–	–	–
Ln(ASH2)	3.60 **	–	–	–	–	–
Ln(AGDD3)	−10.15 **	1.26 **	–	–	–	−2.48 *
Ln(AP3)	−9.78 ***	–	–	–	–	–
Ln(ASH3)	–	–	–	–	–	–
Ln(AGDD4)	−18.12 **	0.96 **	–	–	−0.18 *	–
Ln(AP4)	20.88 **	–	–	–	–	−0.56 **
Ln(ASH4)	11.09 ***	0.20 **	–	–	0.06 **	−0.25 ***

Notes: *, ** and *** represent 0.10, 0.05 and 0.01 levels of statistical significance, respectively.

In the research period, temperature change exerted the greatest impact in Region I (Southern China) compared with other regions according to Table 6. This region has the lowest latitude amongst the six regions. Temperature had a significantly negative effect in growth stages 3 and 4. One of the explanations might be that warming encourages the spread of plant diseases and the survival of insect pests where plant diseases and insect pests are a severe problem for OSR production in this region. Precipitation exerted a significantly positive impact in all the growth stages except in growth stage 3. Sunshine hours of growth stages 1, 2 and 4 had a significantly positive effect on yield, and the sunshine hours impact was also the largest in this region.

In Region II (Huang-Huai plain), the temperature–yield effect was significantly positively signed in growth stages 3 and 4 and precipitation-yield in stages 1 and 2. The sunshine hours effect was significant and positive only at the ripening stage. In fact, the region is susceptible to frequent spring droughts, so increased precipitation is beneficial in early growth stages. As frost damage can be common in early spring, a warming climate is advantageous at this period.

Region III (Yunnan-Guizhou plateau) is characterised by warm winters. Precipitation had a significantly positive impact at growth stages 1 and 2. In Region V, temperature exerted a significantly negative impact on OSR yield at the final stage (ripening stage) and precipitation a significantly positive effect at growth stage 1. Sunshine hours were significantly positive in growth stages 1 and 4.

In general, a rise in precipitation is generally detrimental to OSR yields in Region VI where water-logging can be a problem for OSR production (Yang et al. [27]). Hence, increasing levels of rainfall in future could reduce OSR yields in this region. Temperature had significantly positive impacts in growth stage 2, but were negative in growth stage 3. Sunshine hours had positive effects over growth stages 1 and 4.

6.2. Temporal Pattern of the Impact that Climate Variables Had on Yield

At growth stages 1 and 2 (pre-emergence and seedling emergence, rosette and flower bud development stages), warm conditions improve the metabolism of the OSR plant and help it survive through winter. However, too high a temperature not only affects the vernalisation of OSR (viz. the cooling of seeds during germination in order to accelerate flowering when it is planted) , but also shortens its vegetative stages and can cause its entire reproductive stages to advance, which may result in lodging because of short, slender and weak stem plants. As for growth stage 3 (flowering stage), low temperatures can lead to low ripening rates. The appropriate average temperature for OSR at the ripening stage is between 15 °C and 20 °C. Within this range, lower temperature benefits seed filling. Too much precipitation reduces the permeability of soil, causing root rot, which also reduces yields (Xiao et al. [28]).

We found that generally temperature was critical during the flowering stage and ripening stage. Precipitation was critical through the whole growth period and sunshine hours were critical at the ripening stage. In the research period, for growth stage 1 (pre-emergence and seedling emergence), precipitation was the most influential climatic factor for OSR since it had a significant impact on OSR yield in five regions (Regions I, II, III, V, VI). Growth stage 1 is a stage at which OSR passes through winter in all of these regions. Soil moisture and temperature are the two most important factors controlling germination, root growth and emergence. Temperatures below 10 °C generally result in poor germination and seedling emergence (Canada Canola Council [24]).

However, winter average temperature in China in past 50 years, and especially post-1980s, has increased at a rate of 0.22 °C per 10 years. Winter and spring average temperature increases were the most marked (Ding et al. [25]) and this may account for why temperature was not the most influential climatic factor with respect to yields during these stages in most of the winter-OSR production regions. The impact of precipitation on yield was positive in these five regions except region VI (lower Yangtze River) where waterlogging was noted above to be a problem. By contrast, further upriver in Region V (middle Yangtze), a precipitation increase of 10 mm would raise yields by 0.13%.

For growth stage 2 (stem elongation and flower bud development), precipitation remained the most important climatic factor for OSR in region I, II and III in the research period. It had a significantly positive impact on OSR yield in these regions.

For growth stage 3 (flowering), temperature was the most influential climatic factor in the research period. However, the impact varied in different regions. Temperature had a significantly adverse impact on OSR yields in region I and VI (Southern China, Lower reaches of Yangtze River) especially in region I which is a tropical or subtropical region. Average AGDD values of growth stage 3 in these two regions were quite high, i.e., 403.6 °C and 441.7 °C specifically (see Appendix Table A2).

Sunshine is critical for the development of pods, ass can be seen in Table 7, where sunshine hours had significantly positive impacts in Regions I, II, V at the ripening stage. The final growth stage is at the beginning of summer in these regions, and temperatures can be quite high. Temperature had a significantly negative impact on OSR yield in Regions I and V, which means high temperature damaged OSR yield at the ripening stage in these two regions.

6.3. Impact of Other Factors on Yield

Labour was the most influential physical input factor in most of the regions in the research period. It had a significantly positive impact on OSR yield in these regions, especially in Regions I and VI. In fact, in Hubei province in China, the largest OSR production province, except for land availability which is affected by the growth of industrial development and urbanization, labour is the largest constraint on OSR production (He et al. [17]). Region VI (lower Yangtze River, including Zhejiang province, Jiangsu province and Shanghai city area) is the most economically developed among the OSR regions, and labour demand is high in non-farming occupations. Hence, the yield elasticity of labour input in this region is 0.15, which is the highest among the six regions.

Chemical fertilizers are used intensively in farming in China. The contribution of chemical fertilizer to China's agricultural production used to be around 30% (Lin et al. [29]). However, yield response to chemical fertilizers was not as critical as response to labour in contributing to OSR yields. It had a significant impact in only Regions I, II and V, and the impact was nevertheless smaller than that of labour on OSR yield (see Table 8).

The proportion of OSR area relative to the total farming area had a significantly negative impact on OSR yields in all production regions, implying that the expected a priori positive effect of OSR production specialization was most probably cancelled out by rotational limitations dominating the yield effect. Agricultural income per hectare had a significant impact in four regions, but the impact was negligible. The impacts of age and education were inconsistent in different regions. The annual training farmers undertook had significant positive impacts on yields in region III and V. Farmer status in terms of having an administrative or a managerial village post made no significant contribution to yields.

Table 8. Significant socio-economic variables in each region.

Non-Climatic Variables	I	II	III	IV	V	VI
constant	29.46 *	–	6.85 **	9.50 ***	6.16 ***	11.95 ***
time	1.19 ***	−0.06 ***	–	–	0.02 ***	–
$Ln(l)$	0.15 ***	0.11 ***	–	0.10 ***	0.08 ***	0.15 ***
$Ln(f)$	−0.05 ***	0.03 *	–	–	0.02 ***	–
$Ln(om)$	–	–	–	0.02 *	0.02 ***	–
Age	−0.02 *	–	–	–	–	–
Education	0.06 **	–	–	–	–	–
Training	−0.04 *	–	0.03 ***	–	0.02 ***	–
Social status	–	–	–	–	–	–
Rapeseed area%	−0.71 ***	−0.69 ***	−0.54 ***	−0.53 ***	−0.23 ***	−0.22 ***
Agr. income	0.00 ***	0.00 ***	–	0.00 ***	0.00 ***	–

Notes: *, ** and *** represent 0.10, 0.05 and 0.01 levels of statistical significance, respectively.

7. Conclusions

As the demand for OSR products such as rapeseed oil and cake has been increasing globally and in China, it is essential to understand the susceptibility of production in China to changes in climate. We studied how the yield variability of OSR in China, the world's second largest producer, was impacted by climate variations, identifying the spatial and temporal impacts that climate factors had on yield to provide useful information for policy makers and reference for other OSR producers in the world.

The results identified the impact that climate variables had on the spatial distribution of OSR yields. In general, temperature, precipitation and sunshine hours had significant impacts on OSR yield in all regions except region III (Yunnan-Guizhou plateau) and IV (Sichuan basin). Increase in precipitation and sunshine hours were more likely to have a positive impact. We also found that OSR yields in low-latitude regions were more likely to decrease under warming and were more sensitive to warming as well, which confirms the findings for other crop yields according to the fourth assessment report of the IPCC (IPCC, [10]).

Over the research period, high temperature was more likely to reduce OSR yield in regions I, V and VI, namely Southern China sub-region, and the Middle and Lower Yangtze River. In the major producing Middle Yangtze Region V, accounting for over 30% of China's OSR production, yields responded positively to more sunshine and more rain during crop establishment, but hot and cloudy summers at ripening increased the likelihood of fungal diseases and depressed yields. Wetter and cloudy winters tended to inhibit crop establishment in the Lower Yangtze Region VI which produces around 15% of China's output. Although warmer early springs could benefit yields, associated late spring and hotter summers would be detrimental, as would cloudier, wetter summers, especially if accompanied by periods of greater rain intensity.

Higher temperatures were found to be beneficial for OSR yields in Region II (Huang-Huai plain) which is in northern China at high altitude. What might be expected is that future climate warming may cause more harm to OSR production in Regions I, V and VI. However, OSR production in Region II is more likely to benefit from warming. Even in the Loess Plateau, which is a sub-region in the north of region II and was not studied in the paper, it could be expected that OSR production would benefit from future warming.

However, the impact that climate variables exerted on yields in different growth stages varied. In general, temperature was the most critical climate factor at growth stage 3 (flowering stage) and 4 (ripening stage) in the research period. Precipitation was the most influential climate factor at growth stages 1 and 2 (pre-emergence and seedling emergence stage, stem elongation and flower bud development stage) in the research period. Sunshine hours were the most critical climate factor at growth stage 4 (ripening stage) in the research period.

Labour input, indicative of managerial attention to cultivation, had a significantly positive impact on OSR yields in most of the regions. Simple cultivation techniques are needed for OSR production. Nevertheless, the higher the proportion of the OSR area to the total farming area, the lower the rotational possibilities. Fertiliser input elicited the greatest response in the Middle Yangtze Region IV, which produces the most OSR in China. There will of course be limits to the extent that such inputs might mitigate the longer term impact of climate warming.

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Appendix A

Table A1. Growth stages by time of year and region for winter OSR (There are two ways of planting OSR in China, direct sowing or transplanting. Small-scale farmers tend to transplant OSR plants when the previous crop is not harvested by the direct sowing date of OSR. The sowing date of transplanted OSR is earlier than direct sowing OSR. Thus, there are two sowing dates in growth stage 1. For example, in Guangxi province in region I in S. China, the sowing date of transplanted OSR is 20/09 and that of directly drilled OSR is 15/10. The survey also includes information on how farmers plant OSR).

	Growing Regions	Provinces	Growth Stage 1	Growth Stage 2	Growth Stage 3	Growth Stage 4
I	Southern China	Guangxi	20/09\15/10–19/12	20/12–19/02	20/02–19/03	20/03–25/04
II	Huang-Huai Plain	Anhui	20/09\01/10–09/02	10/02–09/03	10/03–09/04	10/04–20/05
		Henan	20/09\10/10–31/01	01/02–28/02	01/03–31/03	01/04–15/05
III	Yunnan-guizhou Plateau	Yunnan	10/09\01/10–20/12	21/12–19/02	20/02–19/03	20/03–25/04
		Guizhou	10/09\10/10–19/01	20/01–19/02	20/02–24/03	25/03–20/05
IV	Sichuan Basin	Sichuan	15/09\01/10–19/01	20/01–19/02	20/02–19/03	20/03–10/05
		Chongqing	15/09\01/10–19/01	20/01–19/02	20/02–19/03	20/03–20/04
V	Middle reaches of Yangtze	Hubei	20/09\15/10–28/01	29/01–28/02	01/03–31/03	01/04–10/05
		Hunan	01/09\20/09–14/01	15/01–04/03	05/03–04/04	05/04–05/05
		Jiangxi	20/09\10/10–19/12	20/12–19/02	20/02–31/03	01/04–01/05
VI	Lower reaches of Yangtze	Jiangsu	20/09\01/10–28/02	01/03–31/03	01/04–30/04	01/05–01/06
		Zhejiang	01/10\10/10–31/01	01/02–09/03	10/03–09/04	10/04–20/05
		Shanghai	20/09\01/10–28/02	01/03–31/03	01/04–30/04	01/05–01/06
VII	Loess Plateau	Shaanxi	05/09\20/09–28/02	01/03–19/03	20/03–19/04	20/04–01/06

Source: Survey data and information from Provincial Agricultural Departments.

Table A2. Overview of the data used for regression analysis in the model.

Data	Source	Scale	Frequency	Transformation
Yield	survey data	farmer	Yearly	logged
Labour	survey data	farmer	Yearly	Divided by sown area and logged
Fertilizer	survey data	farmer	Yearly	Divided by sown area, and deflated by AMPI and logged
Other input	survey data	farmer	Yearly	Divided by sown area, and deflated by AMPI and logged
Precipitation	1	county	Daily	Accumulated for each growth stage and logged
Temperature	1	county	Daily	Accumulated for each growth stage and logged
Hours of sunshine	1	county	Daily	Accumulated for each growth stage and logged
Age	survey data	farmer	Yearly	–
Education	survey data	farmer	Yearly	–
Training times	survey data	farmer	Yearly	–
Social Status	survey data	farmer	Yearly	–
Rapeseed area%	survey data	farmer	Yearly	–
Agr. income	survey data	farmer	Yearly	–

Note: 1 means that the data were obtained from the China Meteorological Data Sharing Service System.

Table A3. Mean values of main variables in the analysis by region.

Variables	Units	I	II	III	IV	V	VI	VII	ALL
Yield (*y*)	kg/ha	1615.0	2122.2	2167.9	2346.0	2117.1	2716.9	2897.7	2283.2
Conventional inputs									
Labour (*l*)	days/ha	119.5	94.0	154.5	144.4	91.4	127.1	151.6	126.1
Fertilizer (*f*)	RMB/ha	667.5	932.2	733.3	876.2	822.8	933.6	620.3	798.0
Other (*om*)	RMB/ha	432.3	693.7	296.7	467.4	574.3	197.0	532.0	456.2
Climate variables of growth stage 1									
AGDD1	°C	1134.7	1174.7	1183.4	1522.0	1192.6	1553.1	1602.6	1337.6
AP1	mm	96.4	152.1	134.4	172.9	184.8	292.8	196.5	175.7
ASH1	hours	307.6	534.4	314.0	189.0	524.5	583.4	478.1	418.7
Climate variables of growth stage 2									
AGDD2	°C	602.4	152.1	396.51	242.7	336.7	287.9	200.0	316.9
AP2	mm	111.1	46.4	12.0	15.3	109.3	109.5	6.9	58.7
ASH2	hours	99.7	100.5	217.7	41.7	147.1	136.1	89.8	118.9
Climate variables of growth stage 3									
AGDD3	°C	403.6	353.2	374.4	348.4	398.8	441.7	454.6	396.4
AP3	mm	70.6	63.7	22.6	16.1	125.7	78.0	49.4	60.9
ASH3	hours	47.2	159.7	135.8	74.8	114.6	165.7	152.6	121.5
Climate variables of growth stage 4									
AGDD4	°C	714.0	812.9	795.2	736.8	602.2	728.8	873.7	751.9
AP4	mm	154.1	103.1	96.0	87.8	158.5	101.3	140.0	120.1
ASH4	hours	93.8	268.2	191.7	147.1	211.8	208.5	245.0	195.1
Farmer characteristics									
Age	years	48.4	53.5	49.8	55.8	53.1	58.2	50.9	52.8
Education	years	8.9	8.0	8.1	7.6	8.5	8.1	9.5	8.4
Training	No. p.a.	3.2	3.0	2.8	3.9	2.2	2.7	3.3	3.0
Social status		0.2	0.1	0.1	0.2	0.2	0.2	0.1	0.1
Rapeseed area %		0.3	0.4	0.6	0.5	0.6	0.4	0.6	0.5
Agr. income	RMB/ha	22,311.85	22,376.59	31,449.71	27,503.93	25,563.16	23,369.74	22,599.48	25,024.92

Source: Calculated by the authors.

References

1. Ray, D.R.; Gerber, J.S.; MacDonald, G.K.; West, P.C. Climate Variation Explains a Third of Global Crop Yield Variability. *Nat. Commun.* **2015**, *6*, 1–9. [CrossRef] [PubMed]
2. Scealy, R.; Newth, D.; Gunasekera, D.; Finnigan, J. Effects of Variation in the Grains Sector Response of Climate Change: An Integrated Assessment. *Econ. Pap. J. Appl. Econ. Policy* **2012**, *31*, 327–336. [CrossRef]
3. Butler, E.E.; Huybers, P. Adaptation of US Maize to Temperature Variations. *Nat. Clim. Chang.* **2013**, *3*, 68–72. [CrossRef]

4. Asseng, S.; Ewert, F.; Rosenzweig, C.; Jones, J.W.; Hatfield, J.L.; Ruane, A.C.; Boote, K.J.; Thorburn, P.J.; Rotter, R.P.; Cammarano, D. Uncertainty in Simulating Wheat Yields under Climate Change. *Nat. Clim. Chang.* **2013**. [CrossRef]
5. Porter, J.R.; Xie, L.; Challinor, A.J.; Cochrane, K.; Howden, S.M.; Lqbal, M.M.; Lobell, D.B.; Travasso, M.I. Food security and food production systems. In *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects*; Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 485–533.
6. Lobell, D.B.; Schlenker, W.; Roberts, J.C. Climate Trends and Global Crop Production since 1980. *Science* **2011**, *333*, 616–620. [CrossRef] [PubMed]
7. Easterling, W.E.; Aggarwal, P.K.; Batima, P.; Brander, K.M.; Erda, L.; Howden, S.M.; Kirilenko, A.; Morton, J.; Soussana, J.F.; Schmidhuber, J.; Tubiello, F.N. Food, fibre and forest products. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 273–313.
8. Zhang, T.; Zhu, J.; Yang, X.; Zhang, X. Correlation Changes between Rice Yields in North and Northwest China and ENSO from 1960 to 2004. *Agric. For. Meteorol.* **2008**, *148*, 1021–1033. [CrossRef]
9. Zhang, T.; Zhu, J.; Wassmann, R. Responses of Rice Yields to Recent Climate Change in China: An Empirical Assessment Based on Long-term Observations at Different Spatial Scales (1981–2005). *Agric. For. Meteorol.* **2010**, *150*, 1128–1137. [CrossRef]
10. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2007: The Physical Science Basis*; Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007.
11. Wang, S. *Effects of Climate Change on Rapeseed Production in Australia and China*; Northwest Agricultural and Forestry University: Yangling, China, 2014.
12. Evan, N.; Butterworth, M.H.; Baierl, A.; Semenov, M.A.; West, J.S. The Impact of Climate Change on Disease Constraints on Production of OSR. *Food Secur.* **2010**, *2*, 143–156. [CrossRef]
13. Eickermann, M.; Lokys, H.L.; Ulber, B.; Junk, J. Impacts of climate change on the crop invasion of oilseed-rape by the rape stem weevil, Ceutorhynchus napy, in North-Western Germany. In Proceedings of the 20th International Congress of Biometeorology, Cleveland, OH, USA, 3–7 September 2014.
14. United States Department of Agriculture. Available online: www.pecad.fas.usda.gov/cropexplorer/ (accessed on 4 December 2016).
15. FAOSTAT. production and trade databases. Available online: http://faostat.fao.org/ (accessed on 9 March 2017).
16. You, L.Z.; Rosegrant, M.W.; Cheng, F.; Wood, S. Impact of Global Warming on Chinese Wheat Productivity. Available online: http://www.ifpri.org/publication/impact-global-warming-chinese-wheat-productivity (accessed on 4 December 2016).
17. He, Y.Q.; Leng, B.F.; Feng, Z.C. The Impact of Climate Factors on OSR Production in Hubei, China by Using Translog Production Function. *Res. Sci.* **2015**, *37*, 1465–1473.
18. Rowhani, P.; Lobell, D.B.; Linderman, M.; Ramankutty, N. Climate Variability and Crop Production in Tanzania. *Agric. For. Meteorol.* **2011**, *151*, 449–460. [CrossRef]
19. Zhu, M.D.; Jiang, D.P. Where to go? China's Soybean Industry under the Pressure of International Competition. *Res. Agric. Mod.* **2014**, *35*, 543–549.
20. National Statistics Bureau of China. Available online: http://www.stats.gov.cn/ (accessed on 4 December 2016). (In Chinese)
21. Zhang, S.J.; Wang, H.Z. Adaptation to Climate Change of Chinese OSR Production. *Chin. J. Oil Crop Sci.* **2012**, *34*, 114–122.
22. Liu, H.L. *Genetic and Breeding of OSR*; China Agricultural University Press: Beijing, China, 2000; pp. 46–58.
23. Liu, Z.Q. *Study on Sowing Date Effect on Development of Rapeseed (Brassica Napus L.)*; Huazhong Agricultural University: Wuhan, China, 2008.
24. Canada Canola Council. Available online: www.canolacouncil.org (accessed on 4 December 2016).

25. Ding, Y.H.; Ren, G.Y.; Shi, G.Y.; Gong, P.; Zheng, X.H.; Zhai, P.M.; Zhang, D.E.; Zhao, Z.C.; Wang, S.W.; Wang, H.J.; et al. National Assessment Report of Climate Change (I): Climate change in China and its future trend. *Adv. Clim. Chang. Res.* **2006**, *2*, 3–8.
26. China Meteorological Data Sharing Service System. Available online: http://cdc.nmic.cn/home.do (accessed on 4 December 2016).
27. Yang, L.Y.; Wang, W.R.; Li, Y.L. Technology of Prevention and Common Natural Disaster of Rapeseed Production in Shanghai. *Hubei Agric. Sci.* **2009**, *48*, 3163–3166.
28. Xiao, R.Y.; Wang, J.; Ni, Q.H. *Modern Technology of OSR Cultivation*; China Agricultural Science and Technology Press: Beijing, China, 2011.
29. Lin, Y.F. Rural reforms and agricultural growth in China. *Am. Econ. Rev.* **1992**, *82*, 34–51.