Growth period trend analysis both *Triticum aestivum* L. and *Zea mays* L. in Eastern Henan Province: Case study of NDVI3g (1982-2013) in Yongcheng and Xiayi experiment areas

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Abstract. Long-term GIMMS AVHRR NDVI3g (1982~2013) remote sensing image was used to obtain the equivalent biomass of winter wheat and summer maize in Xiayi and Yongcheng experimental sites as well as the change trend of vegetation SOS, EOS and LOS by regression analysis, Gaussian fitting and NDVI volume integration, and combined with climate driving factors (precipitation, temperature) to analyze the correlation between these trends and vegetation index changes. The results showed that (1) The vegetation index of 32a in the study areas showed an increasing trend, the vegetation growth of Yongcheng was better than that of Xiayi, and the NDVI equivalent biomass was higher than that of Xiayi; (2) The SOS of the Yongxia experimental sites was significantly advanced, and the EOS was slightly advanced, resulting in a significant increase in the vegetation growth period in the two study areas, and the increase of vegetation LOS in Yongcheng experimental area was about 3 times that of summer maize. The advancement of LOS was the main way to respond to climate change by vegetation activities in Yongxia areas; (3) The NDVI in the study areas was significantly positively correlated with temperature and had no significant correlation with precipitation.

1. Introduction

The interaction of vegetation and climate has become one of the key scientific issues in crop yield estimation and global climate change research [1]. SOS (start of growing season), EOS (end of growing season) and LOS (length of growing season) are the main indicators for crop growth and the main driving factor for the change of the SOS, EOS and LOS is climate change [2]. Compared with traditional methods such as meteorological model estimation, yield sampling survey, comprehensive crop yield survey, agronomic model estimation, model simulation, etc. [3], remote sensing technology combined with meteorological observation data are used to carry out large-scale crop growth status and biomass assessment, and then proceed production estimation has been around for a long time [4-5]. For example, Chen Huailiang et al. based on NOAA/AVHHR data and the same period meteorological data, found that with the change of climate, the vegetation growing season in Huanghuaihai area was extended from 1982 to 2000 [6]. Xiao Dengpan et al. found that the sowing period of spring wheat in Xinjiang (1981-2009) showed an early trend, while the sowing period of winter wheat mainly showed
a delayed trend; and the sowing period of spring maize and summer maize both showed an advanced trend [1]. Using the 1982-2012 GIMMS NDVI3g data, Gaertner Brandi A et al. found that the SOS in the central Appalachian Mountains region was 16.3 days ahead of schedule on average, the EOS decreased by an average of 10.7 days, and the LOS increased by an average of 22.2 days, and interact with climate, atmospheric humidity and other climatic factors [7]. Using the growth period material and meteorological observation data of summer maize in various areas of the North China Plain from 1981 to 2009, found that the number of days in the whole growth period of summer maize showed a significant increase trend, and the number of days in the growth period of Beijing-Tianjin-Hebei region increased the fastest [8]. Based on the winter wheat phenological data of 16 agricultural meteorological observatories in the North China Plain from 1981 to 2009, Xiao Dengpan et al. found that the sowing period, emergence period and wintering start period of winter wheat in the North China Plain were delayed in the past 30 years, while the greening, flowering and maturity stages showed an early trend [2].

Traditional researches predominantly use information on analysing changes in crop growth from ground stations, which requires a lot of manpower and material resources to obtain. These methods have high accuracy but a small range of application. Taking the Yongcheng and Xiayi experimental sites (hereinafter referred to as Y/X experimental area) in the east of Henan Province as an example, this paper intends to use the latest long-term GIMMS AVHRR NDVI3g (1982-2013) remote sensing data, with some methods to accurately identify the SOS, EOS, LOS and NDVI equivalent biomass of winter wheat and summer maize to understand the growth changes of winter wheat and summer maize main producing areas in China in a timely and dynamic manner, and to provide some reference for formulating grain trade and macro-control policies.

2. Materials and methods

2.1. Research area

Y/X experimental area is located in the southeast of the Huaihe Alluvial Plain, which is in the eastern part of Henan Province, and adjacent to eastern Jiangsu Province, southern Anhui Province, northern Shandong Province, and west to Shangqiu Province. The geographical coordinates of the experimental sites are 33°42′–34°18′N, 115°58′–116°40′E. The geomorphic landscape of the experimental area is characterized by flatlands, with “a semihumid and semiarid” continental monsoon climate. The region is an important grain production base for China, artificial planting mainly agricultural plants such as winter wheat and summer maize (Figure 1).

![Figure 1. Geographic location of the study areas](Note: The upper right is Henan Province SRTM DEM; the main background is the Landcover30 Shangqiu land use classification map, the black area is the construction land, and the white area is the cultivated land.)
2.2. Experimental data
The long-term GIMMS AVHRR NDVI3g dataset (1982-2013) was issued by the NASA Global Monitoring and Model Study Group (ftp://ftp.glcf.umiacs.umd.edu/glcf/GIMMS/). The temporal resolution is 15 days, with a spatial resolution of 8 km×8 km. The data is subjected to radiation correction and geometric coarse correction to further remove the bad line, cloud cover, atmospheric water vapor, etc., and then performs NDVI calculation and synthesis [9]. The calculation formula is NDVI=1000×(b2-b1)/(b2+b1), where b1 And b2 is the first and second channels of AVHRR. The half-month synthetic data were calculated by the internationally accepted maximum value composite (MVC) method. The dataset of 32a covered 768 half-months of synthetic NDVI images.

The meteorological data consisted of annual average temperature and precipitation (1982-2013), which came from the Monthly Report of Surface Meteorological Records (MRMR) published monthly by the Meteorological Data Processing Department in Henan Province. And take 12 meteorological stations from Yongcheng and Xiayi districts for Kriging interpolation [10].

2.3. Methods
Based on the half-month synthetic data, the monthly maximum synthesis and the annual maximum synthesis are performed, and the annual and inter-annual analysis are carried out accordingly.

(1) Gaussian fitting of multimodal curves
Due to the different geographical locations of the study areas, the intra-annual NDVI may show a multi-peak curve. To better describe its trend, the GAUSS Multi-peaks function is introduced:

\[
y = y_0 + \sum_{i=1}^{\text{peaks}} \frac{A_i}{w_i \pi/2} e^{-\frac{(x-x_{ci})^2}{w_i^2}} \quad i = (1,2,3,\ldots, \text{peaks})
\]

For example, a bimodal function can be expressed as

\[
y = y_0 + \frac{A_1}{w_1 \pi/2} e^{-\frac{(x-x_{c1})^2}{w_1^2}} + \frac{A_2}{w_2 \pi/2} e^{-\frac{(x-x_{c2})^2}{w_2^2}}
\]

here, \(y_0\) is the baseline, \(A_1\) and \(A_2\) are the peak areas under the two peaks, that is, the NDVI area integral, and \(w_1\) and \(w_2\) are the full width at half maximum of the two peaks, and \(x_{c1}\) and \(x_{c2}\) are the maximum values of the two peaks, that is, the peak positions.

(2) NDVI trend analysis
The linear regression analysis can be used to analyze the annual NDVI trend, and the annual NDVI time variation characteristics are used to reflect the whole spatial variation feature [11]. The calculation formula is:

\[
\theta_{\text{slope}} = \frac{n \sum_{i=1}^{\text{year}} (\text{NDVI}_i) \left( \sum_{i=1}^{\text{year}} \text{NDVI}_i \right) - \left( \sum_{i=1}^{\text{year}} \text{NDVI}_i \right)^2}{n \sum_{i=1}^{\text{year}} (\text{NDVI}_i)^2 - \left( \sum_{i=1}^{\text{year}} \text{NDVI}_i \right)^2}
\]

where, \(\theta_{\text{slope}}\) is a slope in the annual NDVI regression equation; \(n\) is a time span (unit: year), and NDVI\(_i\) is the NDVI value in the \(i^{th}\) year. When \(\theta_{\text{slope}} > 0\), it indicates that the vegetation coverage shows an increasing trend; when \(\theta_{\text{slope}} < 0\), it indicates that the vegetation index shows a downward trend.

3. Research results

3.1. Intra-annual NDVI characteristics of the experimental sites
The monthly mean value of 32a NDVI is averaged to obtain a month mean line, which is fitted by GAUSS Multi-peaks (Figure 2). Further, the GAUSS function mathematical model of NDVI in Yongcheng and Xiayi districts can be obtained. The goodness of fit \(R^2\) is 0.9382 and 0.9281 respectively:
As shown in Figure 2, the monthly average NDVI in the Y/X experimental sites is distinct, and the overall trend is in the form of a bimodal curve which confirms the local phenological characteristics of planting winter wheat and summer maize [12]. The NDVI of the 12 months of the whole year was higher than 0.3 on average, reaching the first peak in early April (winter wheat growth season), and the NDVI was 0.69, the first valley value of 0.40 appeared in early June (winter wheat harvest season); and the second peak value of 0.74 appeared in early August (summer maize growing season), the second valley value of 0.34 appeared in October (summer maize harvest season).

3.2. Threshold of the SOS and EOS

Using MATLAB® to interpolate and render the NDVI, the stages of vegetation growth cycle were identified and analyzed, and the growth threshold was obtained (Figure 3).

As shown in Figure 3, from November of last year to February of this year, the vegetation index of the two areas performed a continuous low value. The growth of vegetation was almost stagnant due to low temperature, and the NDVI fluctuated sharply at the beginning of February. When the NDVI reached 0.50, the vegetation changes ran up to a relatively stable state; it is easier to judge the EOS in
autumn, when the NDVI dropped to 0.50, the vegetation suddenly left the steady state. The sudden increase or decrease of NDVI value represents the change of water, heat and light conditions, resulting in plants to germination or withering. In this paper, 0.50 is used as the NDVI threshold for the beginning of the vegetation SOS or the beginning of the EOS in the study areas.

3.3. LOS change calculation
For the Y/X experimental sites, the key moments corresponding to the SOS and EOS of each year were identified respectively, and then considering the leap years, calculated the corresponding Julian day and finally determined the day of year (DOY). The difference between the DOY of the SOS and EOS was the length of the LOS (Figure 4). Using linear fitting, we can get the change trend of the SOS, EOS and LOS of the 32a in Yongcheng and Xiayi experimental sites.

As shown in Figure 4, as SOS of the two areas was significantly advanced (the slope of the SOS is -1.901 and -1.911 respectively), EOS was slightly advanced (the slope of the EOS is -0.0855 and -0.1272 respectively), resulting in a significant increase trend in the vegetation LOS in the two study areas (the slope of the SOS is 1.645 and 1.636 respectively). From the time series, the SOS of winter wheat in the two areas fluctuated sharply in the mid-to-late 1980s, which could be speculated that it was caused by planting types and farming methods. Therefore, this paper adopted data from 1990 to 2013 to analyze changes in the LOS (Table 1).

|   | A                              | B                              |
|---|--------------------------------|--------------------------------|
| SOS | $y=2885.26116-1.41565x$       | $y=1678.79661-0.81356x$        |
| EOS | $y=865.22116-0.30565x$        | $y=1112.03435-0.4287x$        |

Substitute 1990 and 2013 into the formula above respectively. During the period of 24a from 1990 to 2013, the SOS of ‘a’ area was 32±3 days ahead of schedule, and the EOS was 7±3 days ahead of schedule; the SOS of ‘b’ area was 18±3 days the SOS of ‘a’ area, and the EOS was 9±3 days ahead of schedule. Due to the existence of calculation errors, the LOS of the two study areas increased by an average of 17 days.

The temporal resolution of monthly synthesized NDVI data was 30 days, so the calculation error of Julian day was ±2.8~3.1 days, and the average error was ±3 days.

3.4. NDVI3g equivalent biomass
Studies have shown that NDVI is positively correlated with surface biomass of vegetation [9], and NDVI is also the basic physical quantity derived from vegetation primary productivity NPP (Net primary productivity) and GPP (General primary productivity) [13].
Theoretically, the annual area integral can be obtained by the Gaussian function which achieved by fitting each year (for example, formula (2) and formula (3)), thereby obtaining the area of a polygon, and then calculating the volume of the irregular cylinder or prism. However, due to the large amount of calculation, and each fitting will inevitably bring in the fitting error (for example, $R^2$ is 0.9281, 0.9382 respectively), the volume of the irregular cylinder will be directly calculated here (Figure 5).

As shown in Figure 5, the LOS of winter wheat is from February to June in each year(Figure 5a, 5b), and the LOS of summer maize is from June to October (Figure 5c, 5d). The monthly mean value of NDVI and the time axis encloses a polygon, and the NDVI forms a multilateral prism. Using the volume calculation module provided by Surfer® 8.0, the NDVI volume of winter wheat and summer maize in Yongcheng is 68.819 and 71.233 respectively (calculated according to the Trapezoidal rule and the Simpson rule, and then take the average); and the NDVI volume of winter wheat and summer maize in Xiayi is 68.787 and 69.423 respectively.

3.5. NDVI growth rate and climatic correlation

(1) The average precipitation in the study areas showed a slight increase trend, but the precipitation decreased significantly in recent years (Figure 6a). The average annual precipitation reached a minimum of 634.4 mm in 1988, but there was a significant change point in 2003, and the precipitation increased sharply to 1254.8 mm. The average precipitation of 32a was 860.18 mm, and the precipitation rising rate was 1.59 mm/a.

(2) The minimum annual average temperature in the study areas was 1984 (13.5 °C), the highest year was 2007 (15.46 °C), and the average temperature in 32a was 14.56 °C. The average temperature in 32a showed a fluctuated trend generally (Figure 6b), and its linear temperature increase rate was 0.34 °C/10a.

(3) Correlation between NDVI3g and climatic factors: climatic factors such as temperature, moisture, and illumination etc. are important factors affecting vegetation phenology activities. The NDVI growth rate slopes of Yongcheng and Xiayi were 0.00296 and 0.00311 respectively. The Pearson correlation coefficients of Yongcheng and Xiayi were: 0.638 (P<0.01, significant on both sides) and 0.573 (P<0.01, significant on both sides) respectively; NDVI had no significant correlation with precipitation.
Figure 6. The relationship between NDVI and precipitation and air temperature in Yongcheng.

4. Conclusions

(1) **Annual growth rate of NDVI3g and trend of the LOS:** The vegetation index of 32a in study areas showed an increasing trend. The annual average NDVI growth rates of Yongcheng and Xiayi were 0.00296 and 0.00311 respectively. During 1990 to 2013, the SOS in Yongcheng was 32±3 days ahead of schedule, and the EOS was 7±3 days ahead of schedule; the SOS in Xiayi was 18±3 days ahead of schedule, and the EOS was 9±3 days ahead of schedule. The LOS of the two study areas increased by an average of 17 days.

(2) **Trend of NDVI3g equivalent biomass:** The NDVI volumes of winter wheat from February to June and summer maize from June to October were 68.819 and 71.233 respectively; The NDVI volumes of winter wheat from February to June and summer maize from June to October were 68.787 and 69.423 respectively. The winter wheat and summer maize in Yongcheng were growing better than that of Xiayi, and the NDVI equivalent biomass was higher than that of Xiayi.

(3) **NDVI3g responses to global climate change:** The study found that the NDVI was significantly positively correlated with temperature, and the Pearson correlation coefficients of Yongcheng and Xiayi were 0.638 (P<0.01, significant on both sides), 0.573 (P<0.01, significant on both sides) respectively, but there was no significant correlation with precipitation.

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References

[1] Xiao D, Qi Y, Wang R 2015 *J. Agricultural Research in the Arid Regions*. 33 189
[2] Xiao D, Tao F 2012 *J. Chinese Journal of Eco-Agriculture*. 20 1539
[3] Bai W, Zhang F 2012 *J. Resource Development & Market*. 28 483
[4] Jiang Y 2015 *D. Chinese Academy of Agricultural Sciences*.
[5] She B. 2017 *D. Zhejiang University*.
[6] Chen H, Liu Y, Du Z 2011 *J. Journal of Applied Meteorological Science*. 22 437
[7] Gaertner B A, Zegre N, Warner T 2019 *J. Science of The Total Environment*. 65 1371
[8] Meng L, Liu X, Wu D 2015 *J. Chinese Journal of Agrometeorology*. 36 375
[9] Myneni R B, Dong J, Tucker C J 2001 *J. Proceedings of the National Academy of Sciences of the United States of America*. 98 14784
[10] Huang Z, Qi X, Fan X 2015 *J. Journal of Irrigation and Drainage*. 34 10
[11] Stow D, Daeschner S, Hope A 2003 *J. International Journal of Remote Sensing*. 24 1111
[12] Li X 2011 *J. Nanjing University of Information Science & Technology*. 1
[13] Xin Z, Xu J, Zheng W 2007 *J. Science in China Series D-Earth Sciences*. 37 1504