Research and Application of 3S Technology-based Crop Information Monitoring System

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Abstract

Based on the basic meteorological remote sensing data in major rice-growing areas in China, this paper studies the impacts of climate changes on rice production in major rice-growing areas, establishes a networked crop growth monitoring system based on cluster analysis and 3S technology and adopts the 3S technology to monitor the growth and growth indices of crops at real time to finally achieve the precise management on regional crops. The research results show that the average diurnal temperature range in the rice growing season from 2003 to 2013 gradually decreased in the rice growing areas in China from north to south. Compared with those in the period from 1980 to 1990, from 2003 to 2013, the average diurnal temperature range in rice growing areas in China decreased by about 5.03% during the rice growing season, and the average total sunshine duration decreased by 12.18%; the total precipitation in the rice growing season increased by about 1.71%, and the total number of days of precipitation decreased by about 1.48%; and the climate potential productivity decreased by about 7.28% - on average, the yield in single-cropping fields decreased by about 8.56% and the yield in double-cropping fields was reduced by about 5.89%. We check the wheat growth indices inversed by the system with the observation data of remote sensing images, and the results show that the RMSE between the measured values and the inversed values from remote sensing images of wheat leaf area index and leaf nitrogen content is 0.4319m$^2$/m$^2$ and 0.3718%, respectively, indicating that the calculated inversed values are consistent with the actual conditions and that the monitoring model proposed in this paper can accurately invert crop growth information. Besides, the distributions of leaf area index and leaf nitrogen content in the same class are almost the same, which means that, the larger the leaf area index and leaf nitrogen content are, the more easily they are classified into one class, and vice versa.

Keywords: 3S, climate resources, temporal and spatial characteristics, crop, information monitoring system.

1. INTRODUCTION

Rice and wheat are the main crops in China. The steady growth of rice and wheat production plays a very important role in maintaining China’s economic stability and food security. As the wheat and rice production areas are widely distributed in China, the temporal and spatial differences are quite obvious in different regions, bringing great uncertainty to the production of rice and wheat.

With the development of computer network technologies, the 3S technology-based crop growth monitoring system can quickly invert and acquire the crop growth information, which is of great practical significance to the rapid development of information agriculture. The 3S technology is the general term for remote sensing technology (RS), geographic information system (GIS) and global positioning system (GPS). So far, it has been widely used in agricultural resource and environmental monitoring, cultivated area measurement, crop yield estimation and growth monitoring. Initially, researchers were using the 3S technology in crop information monitoring. For example, researchers integrated GIS with the models widely used in the agricultural sector and developed practical crop management plans, which achieved a number of results (Jones and Barnes, 2000; Li and Yeh, 2004; Berg, Driessen and Rabbinge, 2002; Tan and Shibasaki, 2003). The GPS technology is mainly applied in acquiring the geospatial information for crop cultivation. Only a few researches have been done in this area (Rudorff et al., 2003). The remote sensing technology is used to obtain the crop growth information through high-altitude or ground spectrum detection, and also to provide decision support in precise management on crops (Wesseling and Feddes, 2006; Xue et al., 2004; Marletto et al., 2007; Delalieux et al., 2007; Guerif and Duke, 1998). The 3S technology integrates the advantages of GPS, GIS and RS. In recent years, 3D technology research have some results in crop growth monitoring, national agricultural monitoring and soil moisture
monitoring (Boegh et al., 2004; Gehring et al., 2004; Zeng et al., 2002; Mathiyalagan et al., 2005; Serôdio et al., 2001).

Based on the basic meteorological remote sensing data in major rice-growing areas in China, in this paper, we study the impacts of climate changes on rice production in major rice-growing areas in China. We use the software Anusplin to carry out grid-to-grid computation of the price production climate resources, and at the same time establish a networked crop growth monitoring system based on cluster analysis and 3S technology. We adopt the 3S technology to monitor the growth and growth indices of crops at real time and process and analyze the satellite remote sensing images with the data extraction technology by extracting effective feature information from the images to finally achieve the precise management on regional crops.

2. TEMPORAL AND SPATIAL CHARACTERISTICS OF CLIMATE RESOURCES FOR AND POTENTIAL PRODUCTIVITY OF REGIONAL CROPS

We study the impacts of climate changes on rice production in major rice-growing areas in China. The meteorological data are from data of basic meteorological elements in China in the period from 1980 to 1990 and from 2003 to 2013. After sorting them, we store them in the database. We use the software Anusplin to carry out interpolating calculation. For the climate resources for rice production, we carry out grid-to-grid computation to generate highly precise meteorological data surfaces.

![Figure 1. Temporal and spatial distribution of average of diurnal temperature in China](image)

Figure 1 shows the average diurnal temperature ranges in the periods – 1980-1990 and 2003-2013. From the figure we can see that, since the 21st century, the average diurnal temperature range in the rice growing season has gradually decreased in China from north to south. The changes in the average diurnal temperature range in the northeast and southwest regions were significant, and in local areas, the difference was even up to 9℃; in central and south regions, the average diurnal temperature range did not change much.

Compared with those in the period from 1980 to 1990, from 2003 to 2013, the average diurnal temperature range in rice growing areas in China decreased by about 5.03% during the rice growing season, and the average total sunshine duration decreased by 12.18%. In the northeastern region, the average diurnal temperature range decreased by about 6-10%, and in some parts of Anhui, Hubei and Yunnan, the decline was even up to 10%-15%. In South China, the average diurnal temperature range was on the rise, with an increase of up to 5% in some areas. The temperature difference between day and night was not conducive to the growth of rice, which has a great impact on rice yield and quality. Therefore, in northeast and central regions of China, rice cultivation control management measures should be taken to reduce the impacts of climate on rice.

Figure 2 shows the comparison of the total precipitations in these two periods. From the figure we can see that, in the period from 2003 to 2013, the total precipitation in the rice growing season increased by about 1.71% over the period of 1980-1990, and the total number of days of precipitation decreased by about 1.48%. Specifically, since the 21st century, the total precipitation in the north region has decreased by about 6%, and the precipitation in the south region has increased significantly by about 10%. The increase in precipitation in the rice growing season is conducive to the increase of rice yield, but excessive precipitation will make the rice yield drop sharply.
Figure 2. Temporal and spatial distribution of total precipitation during the rice growing period in China

Figure 3. Temporal and spatial distribution of rice potential climatic productivity in China

Figure 3 shows the comparison of the climate potential productivity in the rice growing season in different regions in China during the two periods. In these two periods, the average climate potential productivity increased from north to south. In 2003-2013, the climate potential productivity decreased by about 7.28% over the period of 1980-1990. On average, the yield in single-cropping fields decreased by about 8.56% and the yield in double-cropping fields was reduced by about 5.89% By utilizing light and temperature resources and strengthening the selection of high-yield varieties and taking scientific cultivation management technologies and measures, we can further increase the yield of rice.

3. 3 S TECHNOLOGY-BASED CROP INFORMATION MONITORING SYSTEM

3.1 Design and implementation of the system architecture

We adopt the 3S technology to monitor the growth and growth indices of crops and nitrogen nutrition at real time and process and analyze the satellite remote sensing images with the data extraction technology by extracting effective feature information from the images to finally achieve the precise management on regional crops.

The 3S technology-based crop growth monitoring system established is shown in Figure 4, which mainly consists of a data layer, a business logic and a presentation layer from top to bottom. The data layer acquires, stores and manage satellite remote sensing images mainly based on the GIS technology, and provides the cluster analysis function to analyze and process crop information as the basis for classification of thematic maps. The business logic layer is mainly composed of four parts: the RS image processing module serves to process the band information of images and provide relevant calculation parameters; the crop growth monitoring model library is used to identify the impacts fed back by the remote sensing images according to the information stored in the model library and inverse the indices of crops, which for wheat and rice mainly include the contents and accumulated amounts of nitrogen and carbon, content and accumulated amount of photosynthetic pigment and C/N ratio, etc.; the cluster analysis module is mainly used to calculate and analyze the inversion results and perform the clustering of the crop growth indices; the crop growth index chart is used to prepare thematic maps.
based on the calculation and analysis results of the above three or reclassify the crops by reference to the results of crop clustering and produce new thematic maps. Based on the spatial distribution of different categories of crops in the thematic map, the system provides decision-making support in precise management and control on regional crops.

**Figure 4. Growth Monitoring System of Remote Sensing Image**

![Diagram of Growth Monitoring System of Remote Sensing Image](image)

**Figure 5. System Function and Technical Principle**

The main functions and technical principles of the established system are shown in Figure 5. The system uses GDAL to read the acquired remote sensing band information, and then extracts the crop information based on NDVI and inverts its growth indices. The crop growth monitoring system based on RS, GIS and cluster analysis mainly consists of three parts - remote sensing information extraction, crop growth index inversion and cluster analysis. The system inverses crop growth indices mainly by calculating the NDVI values of image primitives:

\[
NDVI = \frac{R_{\text{ni red}} - R_{\text{red}}}{R_{\text{ni red}} + R_{\text{red}}}
\]
\( R_{\text{al}} \) is the reflectivity of the near-infrared band; \( R_{\text{red}} \) is the reflectivity of the red band. By comparing the calculation results and the standard NDVI range for crops, we can determine the crop variety.

The inversion of crop growth indices mainly involves the inversion and monitoring of crop growth indices, physiological indices and crop yield and quality. Crop growth indices mainly include crop leaf area index and aboveground biomass; physiological indices of crops mainly include pigment content and accumulation, carbon content and accumulation, nitrogen content and accumulation and C/N ratio; the seed quality indicators include protein content and accumulation and starch content and accumulation. The system reads the appropriate band data in the remote sensing images according to the band information used in the crop growth monitoring model and inverts the crop growth indices.

3.2 Test results and analysis

The test data were acquired from the meteorological data at 340 meteorological stations in major wheat and rice producing areas in China from 2003 to 2015. These data were sorted and stored in the system database. The original data are the digital elevation maps provided by the International Agricultural Research Institute. We adopt the IDW method to carry out the interpolating calculation – calculating the weighted average with the distance between the interpolating point and the sample as the weight:

\[
Z = \left( \frac{\sum_{i=1}^{n} \frac{Z_i}{d_i^p}}{\sum_{i=1}^{n} \frac{1}{d_i^p}} \right)
\]

(2)

\( Z \) is the estimated value by interpolation; \( Z_i \) is the observed value at the \( i \)-th observation point; \( d_i \) is the distance between the interpolating point and the observation point; \( n \) is the sample size; \( p \) is the power exponent. We use \( \text{RMSE} \) to measure the accuracy of the interpolation method:

\[
\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (A_i - E_i)^2}
\]

(3)

\( A_i \) is the observed value at the \( i \)-th site; \( E_i \) is the estimated value by interpolation at the \( i \)-th site.

Based on the above methods, the system inverses the crop growth indices. Take wheat for example. The system uses the NDVI threshold value to extract the remote sensing information on the wheat fields, masks the non-wheat fields in the remote sensing images and carries out the quantitative inversion according to the wheat monitoring module in the crop growth monitoring model library. The calculation results of the leaf area index and leaf nitrogen content of wheat are shown in Figure 6., where the horizontal axis stands for the observed

**Figure 6.** Calculation result of leaf area index and leaf nitrogen content in wheat inversed.
values of the leaf area index and leaf nitrogen content from remote sensing images, and the vertical axis stands for the estimated values of both.

We check the wheat growth indices inversed by the system with the observed data from remote sensing images. From the figure, we can see that the RMSE between the measured values and the inversed values from remote sensing images at 10 wheat leaf area index and 9 leaf nitrogen content sampling points is 0.4319m²/m² and 0.3718%, respectively, indicating that the calculated inversed values are consistent with the actual conditions and that the monitoring model proposed in this paper can accurately invert crop growth information.

**Table 1** Clustering Results of Leaf Area Index and Leaf Nitrogen Content

<table>
<thead>
<tr>
<th>Number</th>
<th>Leaf area index (m²/m²)</th>
<th>Leaf nitrogen content (%)</th>
<th>Classification Probability</th>
<th>Samples number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(1.88, 2.21)</td>
<td>(2.03, 2.25)</td>
<td>0.07</td>
<td>495191</td>
</tr>
<tr>
<td>2</td>
<td>(3.22, 4.15)</td>
<td>(3.06, 3.89)</td>
<td>0.15</td>
<td>690177</td>
</tr>
<tr>
<td>3</td>
<td>(1.79, 2.07)</td>
<td>(1.96, 2.33)</td>
<td>0.07</td>
<td>410893</td>
</tr>
<tr>
<td>4</td>
<td>(1.47, 1.88)</td>
<td>(1.86, 2.09)</td>
<td>0.06</td>
<td>397560</td>
</tr>
<tr>
<td>5</td>
<td>(4.05, 5.17)</td>
<td>(3.22, 4.01)</td>
<td>0.16</td>
<td>779131</td>
</tr>
<tr>
<td>6</td>
<td>(2.99, 3.45)</td>
<td>(3.22, 4.15)</td>
<td>0.14</td>
<td>629014</td>
</tr>
<tr>
<td>7</td>
<td>(1.22, 1.65)</td>
<td>(1.71, 1.93)</td>
<td>0.04</td>
<td>109783</td>
</tr>
<tr>
<td>8</td>
<td>(2.62, 3.06)</td>
<td>(3.17, 3.56)</td>
<td>0.05</td>
<td>233816</td>
</tr>
<tr>
<td>9</td>
<td>(1.01, 1.33)</td>
<td>(1.39, 1.77)</td>
<td>0.04</td>
<td>133079</td>
</tr>
<tr>
<td>10</td>
<td>(2.48, 2.89)</td>
<td>(2.34, 2.67)</td>
<td>0.06</td>
<td>396518</td>
</tr>
</tbody>
</table>

We further use the expectation maximization (EM) algorithm to process the inversion results of the leaf area index and leaf nitrogen content from remote sensing images for single index classification. During the classification, the algorithm automatically calculates the number of classes, and the results are shown in Table 1. The EM algorithm can obtain the relations between different classes according to the classification probability. The classification results provided by the EM algorithm have overlaps on the boundaries, based on which we can determine the connection areas between different classes so as to reduce classification errors.

The wheat leaf area index is the most basic index to represent its canopy structure, while the leaf nitrogen content represents the plant nitrogen status and soil fertility, both of which are closely related. The system established automatically clusters the leaf area indexes and the leaf nitrogen contents into 10 classes. The distributions of leaf area index and leaf nitrogen content in the same class are almost the same, which means that, the larger the leaf area index and leaf nitrogen content are, the more easily they are classified into one class, and vice versa. The system uses the clustering model to process and analyze the remote sensing image information, and finally provides the general description of the remote sensing image data.

**4. CONCLUSION**

Based on the basic meteorological remote sensing data in major rice-growing areas in China, in this paper, we study the impacts of climate changes on rice production in major rice-growing areas in China. We use the software Anusplin to carry out grid-to-grid computation of the price production climate resources, and at the same time establish a networked crop growth monitoring system based on cluster analysis and 3S technology. We adopt the 3S technology to monitor the growth and growth indices of crops at real time and process and analyze the satellite remote sensing images with the data extraction technology by extracting effective feature information from the images to finally achieve the precise management on regional crops. The research conclusions are as follows:

(1) The average diurnal temperature range in the rice growing season from 2003 to 2013 gradually decreased in the rice growing areas in China from north to south. Compared with those in the period from 1980 to 1990, from 2003 to 2013, the average diurnal temperature range in rice growing areas in China decreased by about 5.03% during the rice growing season, and the average total sunshine duration decreased by 12.18%; the total precipitation in the rice growing season increased by about 1.71%, and the total number of days of precipitation decreased by about 1.48%; and the climate potential productivity decreased by about 7.28% - on average, the
yield in single-cropping fields decreased by about 8.56% and the yield in double-cropping fields was reduced by about 5.89%.

(2) We check the wheat growth indices inversed by the system with the observation data of remote sensing images, and the results show that the RMSE between the measured values and the inversed values from remote sensing images of wheat leaf area index and leaf nitrogen content is 0.4319m²/m² and 0.3718%, respectively, indicating that the calculated inversed values are consistent with the actual conditions and that the monitoring model proposed in this paper can accurately invert crop growth information. The calculation results of the expectation maximization (EM) algorithm show that the distributions of leaf area index and leaf nitrogen content in the same class are almost the same, which means that, the larger the leaf area index and leaf nitrogen content are, the more easily they will be classified into one class, and vice versa.

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