Winter wheat quality monitoring and forecasting system based on remote sensing and environmental factors

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Abstract. To achieve dynamic winter wheat quality monitoring and forecasting in larger scale regions, the objective of this study was to design and develop a winter wheat quality monitoring and forecasting system by using a remote sensing index and environmental factors. The winter wheat quality trend was forecasted before the harvest and quality was monitored after the harvest, respectively. The traditional quality-vegetation index from remote sensing monitoring and forecasting models were improved. Combining with latitude information, the vegetation index was used to estimate agronomy parameters which were related with winter wheat quality in the early stages for forecasting the quality trend. A combination of rainfall in May, temperature in May, illumination at later May, the soil available nitrogen content and other environmental factors established the quality monitoring model. Compared with a simple quality-vegetation index, the remote sensing monitoring and forecasting model used in this system get greatly improved accuracy. Winter wheat quality was monitored and forecasted based on the above models, and this system was completed based on WebGIS technology. Finally, in 2010 the operation process of winter wheat quality monitoring system was presented in Beijing, the monitoring and forecasting results was outputted as thematic maps.

1. Introduction

It is important to monitor and forecast the wheat grain protein content. Quality trend forecasting gives guidance for optimization cultivation so as to achieve a high yield and good quality at the wheat growth stage. Similarly, the monitoring could be used to guide farmers for classification harvest, hierarchical storage, and sell accordance with quality[1].
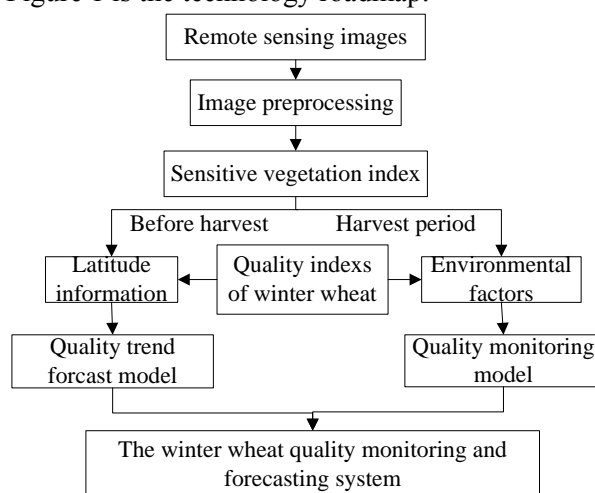
Remote sensing technology is based on principle of spectroscopy, which was used to detect the earth's surface synchronously on a large scale regions without destroy. Therefore it is feasible to monitor aboveground vegetation nitrogen content by remote sensing technology, and futher monitor crop grain quality[2]. However, remote sensing technology could not fully reflect the impact of ecological factors on the quality of wheat. It is necessary to monitor and forecast crop grain quality by combining remote sensing parameters with environmental factors [3].

The modeling is divided into two parts in this paper, wheat quality trend forecasting and quality monitoring. Vegetation index of remote sensing, latitude and agronomy parameters were added to the trend forecast model, and environmental factors were combined into the quality monitoring model. And the winter wheat remote sensing quality monitoring and forecasting system was established based on the above models.

2. Goals of the study

Study area was located in Beijing. The forecasting and monitoring model of winter wheat protein were established and proved to have higher accuracy and applicability. The system that combined spatial information technology, network technology, computer technology was tested stably and with good human-computer interaction. Figure 1 is the technology roadmap.

Figure 1. The technology roadmap of this study

3. Materials and Methods

3.1. The study area and data sources

The study area is the main wheat production regions of Beijing. Quality test was from 2009 to 2010. Winter wheat managed with conventional fertilizer and water consumption. The winter wheat area represents the region's growth and quality characteristics.

Ground sample point data: at winter wheat early growth stages, the visible spectrophotometer and Kjeldahl method were used to measure chlorophyll content and leaf's total nitrogen content, respectively. Wheat grain protein content was measured using near-infrared grain analyzers. Data of soil nutrient was obtained from Beijing Agricultural Technology Promotion laboratory. Meteorological data was provided by Beijing Meteorological Bureau.

Remote sensing data: the U.S. TM (Thematic Mapper) images and images of China Environment and Disaster Reduction Small Satellites that with independent intellectual property rights were used. Two images were selected as test data (HJ satellite data, April 23, 2010 and TM data May 17, 2009) at the key growth period of winter wheat.

Images were processed with geometric correction, radiometric calibration and atmospheric correction because of geometric distortion and radiation distortion exists in raw satellite image data. Support Vector Machine method was implied to classify and then the wheat area was extracted. The normalized difference vegetation index (NDVI) is widely used in crop remote sensing monitoring and forecasting, as effects of solar elevation angle, satellite observation angle, terrain, cloud or shadow can be partly eliminated after the ratio process. Many studies have shown that NDVI is related to LAI, green biomass, photosynthesis and other vegetation parameters, making it an effective indicator for

monitoring regional or global vegetation and environmental changes[3]. Formula 1 is the NDVI calculation:

$$NDVI = (B_{nir} - B_{red}) / (B_{nir} + B_{red})\qquad(1)$$

B_{nir} is the near-infrared spectral reflectance of the remote sensing data and B_{red} is the red band reflectance[4]. NDVI is a remote sensing parameter to monitor and forecast winter wheat quality in this study.

3.2. Quality trend forecast
The biochemical composition of the leaves or stem cannot be used as indicators of the quality evaluation directly, but the good relationship between the remote sensing data and the processed leaves or stem biochemical component makes them a good one [7].

Studies have shown that[5-8] leaf nitrogen content, leaf chlorophyll content at the early stage of wheat growth could reflect grain quality. Latitudes can reflect ecological and meteorological environment. Grain quality changes in different latitudes, which was shown in studies [9-11]. NDVI, latitude and leaf chlorophyll content were analyzed as indicators in this paper to establish the winter wheat quality forecasting model.

Two models were set, linear regression model that combined with chlorophyll A, fresh total chlorophyll, NDVI and the other one is constituted of NDVI and latitude. Models and the contrasted results are listed in table 1.

Table 1. Comparison of Winter wheat quality forecasting models

The dependent variable (y,mg/g)	Independent variables (x)	Regression equation	Correlation coefficient (R)
chlorophyll A (CHL_A)	NDVI	$y = -0.95x + 2.426$	0.426
	NDVI,LAT	$y = -0.834x_1 + 0.203x_2 - 0.761$	0.481
Fresh total chlorophyll (CHL_AB)	NDVI	$y = -1.108x + 3.054$	0.370
	NDVI,LAT	$y = -0.847x_1 + 0.453x_2 - 15.223$	0.525

The results represent that the model of remote sensing index combined with latitude gets higher accuracy compared to the simply agronomic parameters - vegetation index model.

3.3. Quality monitoring of remote sensing
The winter wheat quality is affected by external environmental, such as climate, soil and cultivation practices in addition to the heredity, which cannot be monitored by remote sensing technology. The composite monitoring model that combined of ecological factors gets higher accuracy than single remote sensing variable model, which is consistent with these researches[12,13]. The neural network method was implied by Dacheng Wang to assess the relative and importance of wheat grain protein impact factors, including temperature, rainfall, illumination and soil nutrient content. The illumination time in late May, the rainfall in May, soil nitrogen content and the accumulated temperature in May constituted of final indexes to obtain better monitoring accuracy[3]. The referred environmental factors in winter wheat quality monitoring model in this article are based on Dacheng Wang's work.

Meteorological data of eight meteorological stations in 2009 of Beijing was collected. The meteorological data of eight meteorological stations was used for spatial interpolation, a module in ArcGIS desktop software. Sampling points of meteorological data was extracted in accordance with latitude and longitude of winter wheat. Quality of winter wheat was assessed by grain protein content. Model that referring remote sensing parameters and the one that added environmental factors were varied. The contrastive table 2 is as follows.

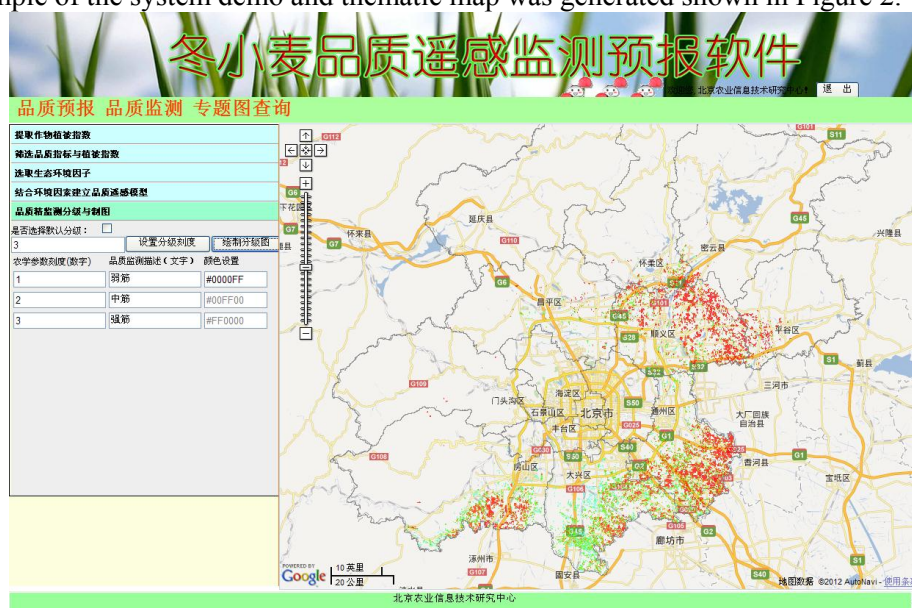**Table 2.** The comparison of Winter wheat quality monitoring models

Type	Regression equation	Correlation coefficient (R)
Univariate models	$Y = 3.745X_1 + 10.581$	0.348
Composite Model	$Y = 7.34X_1 + 0.446X_2 - 0.141X_3 + 1.366X_4 - 0.113X_5 - 307.446$	0.668

Note: Y is grain protein content, and X_1, X_2, X_3, X_4, X_5 separately stand for NDVI, accumulated temperature in May, light of late May, rainfall in May and soil nitrogen content. The model that combined remote sensing parameters with environmental factors gets higher accuracy.

4. The system realization and application

The system was developed in Asp.net platform combined with C# and JavaScript, and Microsoft IIS6.0 was the network server. It uses the ArcGIS Server technology to achieve the information release and Oracle + ArcSDE to realize storage and management of spatial data. The administrative map and thematic maps of the winter wheat quality monitoring and forecasting were superimposed and display by invoking Google maps. The IDL language realized remote sensing image pre-processing and vegetation index calculation, which obtained good development cycles and running speed. The Ajax technology achieved interaction and asynchronously refreshing pages.

The system is divided into three functional modules, the quality trend forecasting, quality monitoring and thematic maps queries, respectively. The quality trend forecasting module combined with latitude fits for wheat in the early growth stage, and quality monitoring module along with environmental factors fits for wheat in harvest time. The 2010 Beijing winter wheat quality monitoring was as example of the system demo and thematic map was generated shown in Figure 2.

Figure 2. Winter wheat quality monitoring thematic map in Beijing 2010

5. Conclusion and discussions

On the basis of previous studies, models combined remote sensing parameters with environmental factors were established. The quality trends forecasting model refers to the early harvest of winter wheat and quality monitoring model refers to harvest time. Both get higher accuracy than the simply agronomic parameters - vegetation index model.

The system, which integrated of the above model and developed by WebGIS technology, provides modules of sample points query, modeling and the thematic maps release with succinct interface and

operability. It is worth mentioning that the sensitive band, vegetation index and the related environmental factors that affecting winter wheat quality needs further excavated.

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