Research and Realization of Winter Wheat Yield Estimation Model Based on NDVI Index

Wu Zhichao[1,2,3,4], Li Changchun[1(✉)], Feng Haikuan[2,3,4(✉)],Xu Bo[2,3,4],Yang Guijun[2,3,4], Li Zhenhai[2,3,4], Pei Haojie[1,2,3,4], Liu Mingxing[1,2,3,4]

[1] School of Surveying and Land Information Engineering, Henan Polytechnic University, Jiaozuo 454000, China

{WZC032018,xmljphj}@163.com,

{lichangchun610,liumingxingreal}@126.com

[2]National Engineering Research Center for Information Technology in Agriculture, Beijing,100097, China

{fenghaikuan123,guijun.yang}@163.com,

lizh323@126.com

[3] Key Laboratory for Information Technologies in Agriculture, the Ministry of Agriculture, 100097, China

[4]Beijing Engineering Research Center of Agricultural Internet of Things, Beijing, 100097, China

Abstract: The timely and accurate prediction of crop yield is of great significance to the formulation of national grain policy, the macro control of prices and the development of rural economy . In this paper, the NDVI values were calculated by using the measured spectral reflectance data of Winter Wheat during the whole growth period in 2014, combining with actual measured output, constructing a function model of NDVI index and measured output. The study concluded that the coefficient of determination (R2) of the NDVI index and the measured yield model in the whole growth period was 0.78, the root mean square error is 40.795 (kg/mu), Standard root mean square error is 10.79%. The value of root mean square error of verification model is 49.297 (kg/mu), the value of standard root mean square error is 13.04%. Therefore, the estimation model obtained in this experiment has good reliability, It is feasible that the portable instrument for measuring the parameters of crop growth potential by using the estimation model.

Key words: total growth period, winter wheat, reflectance, NDVI, measured yield

1 Introduction

Since the 1970s, remote sensing technology has been used in large area crop yield prediction. Precision agriculture has become an important modern agricultural production mode to improve the utilization rate of agricultural resources, reduce the cost of agricultural production and improve the agricultural ecological environment [1].As an important grain crop in China, the safe production of wheat is an important guarantee for the sustainable development of our country. Quickly and timely understanding of the distribution of wheat, generalization, growth status and yield dynamics, to facilitate government decision-makers and producers to take various regulatory measures to achieve the purpose of increasing production, income and efficiency [2]. Estimation of crop yield has gone through the sampling survey, statistical analysis, statistical model and meteorological satellite remote sensing data estimation stage [3]. China's yield estimation by remote sensing are summarized as follows: Spectral information - index - growth information - yield, spectrum - moisture and nitrogen - yield, spectral information - index - growth information - growth model – yield [4]. Many experts and scholars have studied the NDVI index based on the spectral reflectance of different crops ,He hen et al. [5]research

shows that the growth trend in the 3-5 month NDVI index, but the amplification of index was smaller, the production precision is highest in the May NDVI index;others believe that the current work of remote sensing is mainly by using single fertility period or some fertility period of spectral vegetation index and yield for regression analysis to estimate yield, such as NDVI index in China [6-9].
In this study, ASD spectroscopy was used to obtain reflectance data of crops during the whole growth period, calculate NDVI index and yield inversion. The reliability of the instrument is verified indirectly. At the same time, it lays a foundation for large-scale production forecasting.

2 Materials and methods

2.1 Overview of the study area

The experimental area is located in Changping District, Beijing National Precision Agriculture Research and Demonstration Base, located at latitude 40 ° 11 ', longitude 116 ° 27', altitude 36 m, the base of fertile land, flat terrain, soil type for the soil base, covers an area of about 2500 acres, climate type is a typical warm temperate semi-humid continental monsoon climate, the winter wheat crop is the base in late September early October planted.

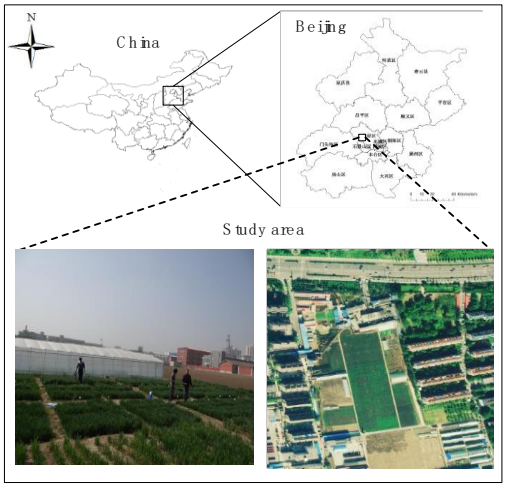


Fig. 1 National Precision Agriculture Research and demonstration base

2.2Research design

There are two varieties of wheat used in this experiment, A and B, respectively, cross planting. There were 16 plots in the test field, and each plot was divided into three sub-districts for three replicates, each with an area of 48 m² (6 m x 8 m) and a line spacing of 15 cm. The experimental field also conducted nitrogen treatment(N1, N2, N3, N4) and water treatment (excessive, normal and rainfed). This experiment is to obtain the reflectance of crops, and the function of dealing with the corresponding NDVI index, the final function model using the measured output and the NDVI index to establish the estimation. Therefore, we should try to reduce the impact of irrelevant factors, so that the experiment from the normal water area selected experimental plots, such as the block 3,6,7,10,11,15 six plots. Among them, using the data of the three plots 3, 6, 10 and 11 to establish the function model of different band length and reflectance.The experimental data of 12 cells were selected from 18 experimental communities to establish the functional model of the corresponding NDVI index in the measured area. The experimental data of the other six communities were used to validate the model.

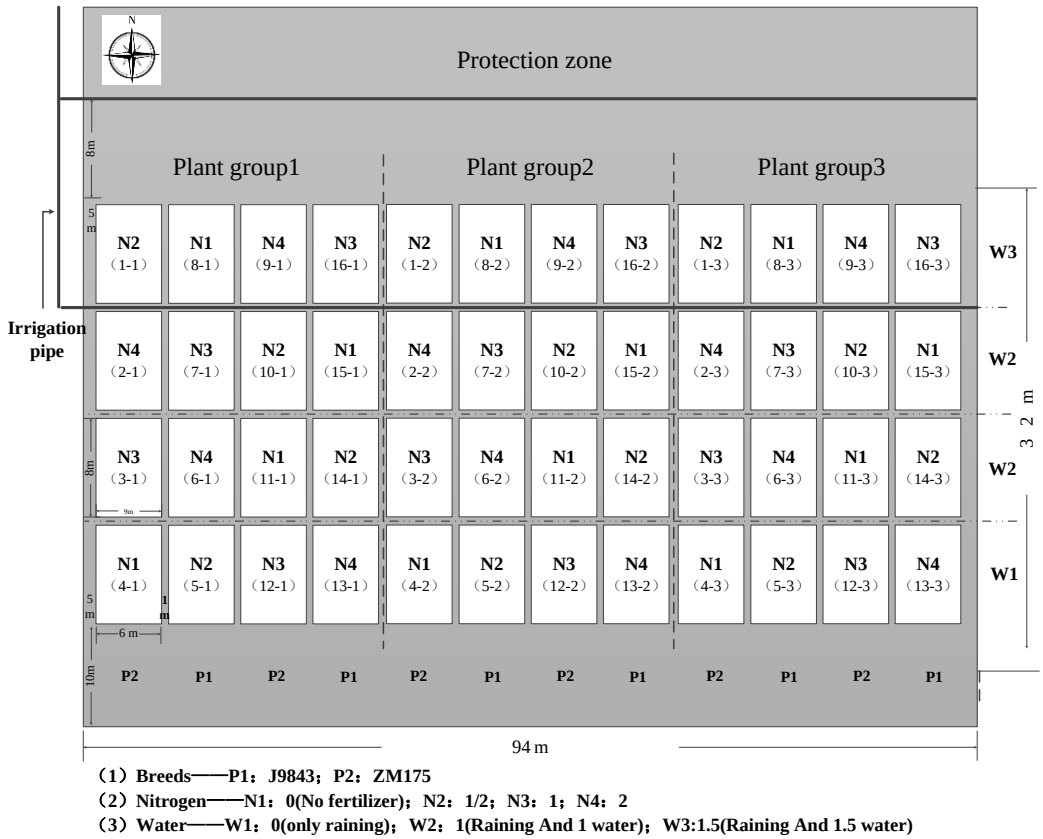


Fig. 2 Sketch map of experimental plots

2.3Instrument introduction

The following is a portable instrument for measuring crop growth parameters (Before using the instrument, the integrating sphere is used to perform spectral calibration on the instrument to ensure that the instrument can be used normally，and the basic parameters of the instrument are as follows).The instrument has two channels. By searching the relevant research status at home and abroad, the final choice is 650nm and 810nm as the channel wavelength of the instrument. The experiment date is from March 28 to May 17; the test time is 6:30 to 18:30, every half an hour to conduct a test. Before the experiment，the equipment should be set up and checked first, the instrument's sensor is facing the sun and level, and the sensor probe is 0.5 meters from the canopy of the rice. Each collection area needs to collect 5 points of data, take the average as the spectral reflection of the sample point.



Fig. 3Instrument for measuring crop growth parameters

Table 1 Hand-held portable crop growth parameters Speedometer parameters

Parameter	Parameter value	Parameter	Parameter value
Operating Wavelength RED	P=650nm±2 nm, FWHM 10nm	Operating Wavelength NIR	p=810nm±2 nm, FWHM 10nm
Relative indication error	8%	Non - linear error	1%
Up sensor	180°	Down sensor	36°

2.4 Determination method

2.4.1 Spectral data

The winter wheat canopy spectra were measured using a FieldSpec Pro FR2500 back-hanging field hyperspectral radiometer manufactured by American Analytical Spectral Device (ASD), the band value is 350-2500nm.The canopy spectra were measured from 6 a.m. to 16 p.m., with clear weather, no wind or very small wind speed. When it was measured, the sensor probe is vertical downward, the vertical height is about 1m from the top of the canopy, and 10 sampling spectra are recorded at each observation point, and the average value is taken as the reflection value of the observation point. In the process of measurement, the standard white board correction should be carried out before and after the observation of each group of targets (the standard white board reflectivity is 1, so the target spectrum is dimensionless relative reflectivity).

2.4.2 Normalized difference vegetation index

NDVI: Refers to the increase in the near infrared range of green leaves scattering and red band range of chlorophyll absorption differences, generally used to detect vegetation growth status, vegetation coverage and eliminate partial radiation errors. In terms of the normalized difference vegetation index, the sensitivity will decrease when the LAI value is very high (LAI is the leaf area index), that is, when the vegetation is luxuriant. Calculation formula:

$$\text{NDVI}=\frac{\rho_{NIR}-\rho_{RED}}{\rho_{NIR}+\rho_{RED}}=\frac{NIR-R}{NIR+R} \quad (1)$$

The range of NDVI value is -1~1, a negative value indicates that the ground cover for cloud, water, snow, high reflection of visible light; 0 said that the rocks or bare soil, NIR and R are approximately equal; positive, said there is vegetation cover and increases with increasing coverage; 0.2~ 0.8 is the general scope of green vegetation area[10].

2.4.3 Yield

This experiment was carried out on the basis of the experimental data（yield、asd）in 2014.The maximum measured output is 549.42(kg/mu), the minimum is 223.03(kg/mu), and the average value is 378.05(kg/mu).Then, the NDVI index and the measured output are used to establish the model, and the NDVI index is tested to calculate the predicted output, and the corresponding RMSE and NRMSE are calculated.

2.5 Model accuracy evaluation

2.5.1 Validation techniques

In this paper, we use 2/3 of the experimental data to establish the model, another third of the experimental data were validation for the model just created. In this paper, a total of 6 plots and 18 plots were selected for the experiment. The experimental data of 12 plots were randomly selected to establish the function model. The experimental data of 6 other plots were used to validate the model.

2.5.2 Coefficient of determination

The coefficient of determination (coefficient of - determination, R) was used as the evaluation of the relationship between remote sensing estimation of biomass and biomass measurement standard. Calculation formula:

$$R^2=\frac{(\sum xy-\frac{\sum x\sum y}{n})^2}{(\sum x^2-\frac{(\sum x)^2}{n})(\sum y^2-\frac{(\sum y)^2}{n})} \quad (2)$$

x、y stands for sample value, n stands for sample number; n stands for the number of samples. The higher the R^2 ,the better the correlation between the variables involved in the evaluation, the higher the reference value; The smaller the R^2,the lower the correlation, the smaller the reference value[11].

2.5.3 Root mean square error

Root mean square error was used as a standard for evaluating the estimated biomass and measured biomass errors.

Calculation formula:

$$RMSE=\sqrt{\frac{\sum_{i=1}^{n}(y_i-\hat{y}_i)^2}{n}} \quad (3)$$

$$NRMSE=RMSE/X \quad (4)$$

y_i stands for measured value, $\hat{y}_i$ stands for analog value, n stands for the number of samples, X stands for mean of the measured value. RMSE is very sensitive to larger errors. The smaller the RMSE, the higher the accuracy of the estimation results. RMSE has increased the penalty for single data (squared penalty), which makes the evaluation even more rigorous[12]

2.6 Statistical Analysis

In this study, determination coefficient（R^2）and root-mean-square error were regarded as indicators to interpret and quantify the relationship between NDVI and vegetation index. Generally speaking, the higher R^2, the smaller RMSE, and the better ability of the estimated model between the NDVI and vegetation index, otherwise, the estimated ability is poor.

3 Results and Analysis

3.1 The relationship between the length and reflectivity of different plots of Winter Wheat in different bands

Refer to the literature at home and abroad indicated that the relationship between the length and reflectivity of Winter Wheat in different bands is linear regression model. From the measured data, the interception wavelength is between 640-660nm and 800-820nm. The function models of different band length and reflectivity of each block are obtained as follows:

Table 2 The relationship between band and reflectivity in 640-660nm

Block number	Relationship between long pulse and reflectance	Coefficient of determination(R^2)
3	y = -0.0001x + 0.1246	0.9851
6	y = -0.0002x + 0.1473	0.9886
10	y = -0.0001x + 0.1182	0.9846
11	y = -0.0002x + 0.178	0.9818

Table 3 The relationship between band and reflectivity in 800-810nm

Block number	Relationship between long pulse and reflectance	Coefficient of determination(R^2)
3	y = 0.0002x + 0.2049	0.9262
6	y = 0.0002x + 0.2316	0.9454
10	y = 0.0002x + 0.1878	0.9622
11	y =0.0002x + 0.1214	0.9799

3.2 A functional model for measuring NDVI index of yield and whole growth period was established

This study is based on the average reflectance of different bands of crops obtained in each plot obtained in 2014.The corresponding NDVI index is obtained by formula (1-1), following table

Table 4 NDVI index of each experimental plot

Cell ID	NDVI index	Cell ID	NDVI index
p03-1	0.86	p10-1	0.83
p03-2	0.89	p10-2	0.85
p03-3	0.78	p10-3	0.82
p06-1	0.82	p11-1	0.54
p06-2	0.85	p11-2	0.74
p06-3	0.84	p11-3	0.56
p07-1	0.84	p15-1	0.85
p07-2	0.86	p15-2	0.68
p07-3	0.84	p1 5-3	0.73

The measured output and NDVI data of 12 plots were obtained and analyzed statistically，obtained the function model of measuring yield and NDVI index, as follows. The relationship between measured yield and NDVI index is $y = 45.504e^{2.6504x}$,The R^2 is 0.78 by using formula (1-2),the RMSE is 40.795(kg/mu) by using formula (1-3),the NRMSE is 10.79%.The above data show that the model the model has certain reliability.

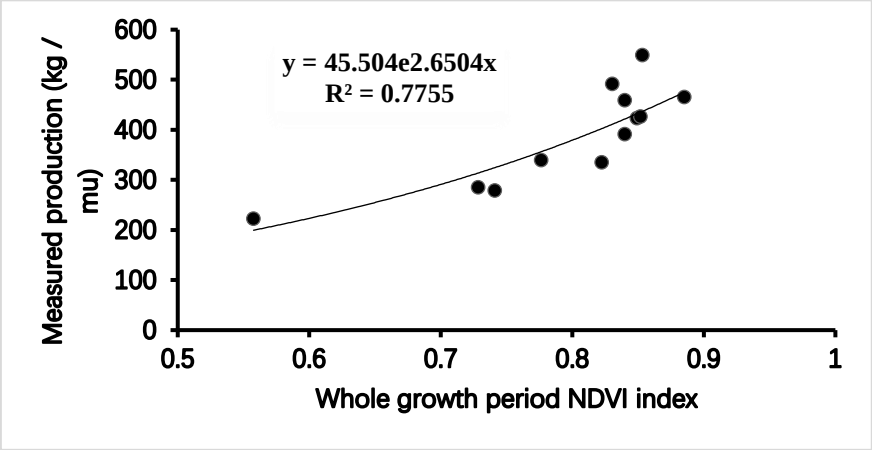


Fig. 1 NDVI index and measured yield model for full growth period

3.3 Verification of function model

Using the NDVI index of the other six communities that did not participate in the model building are respectively used in the function model obtained in the previous section. Compared with measured output, calculated the RMSE is 49.297 (kg/mu) by using formula (1-3), the NRMSE is 13.04%. The above data show that the model has certain reliability.

4 Conclusion

(1)When the band length is 640-660nm, the fitting model of band length and crop reflectivity is higher, and the influence of nitrogen treatment is smaller. When the band length is 800-810nm, the fitting degree of normal nitrogen and nitrogen treatment is higher than that of semi nitrogen and nitrogen free treatment.

(2)The estimation model established by using yield and NDVI index measured the decision coefficient R value is 0.78, the root mean square error of the value of RMSE is 40.795 (kg/mu), mean

square error NRMSE value is 10.79%.

(3)When model validation is performed, the root mean square error RMSE is 49.297 (kg/mu), and the standard root mean square error is 13.04%.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China (No.41601346) and National Key Research and Development Programs (2016YFD0300603).

Reference

[1] Wang Xi.Study on variable rate fertilization control of soybean in precision agriculture [D]. Heilongjiang Province , Daqing City: Heilongjiang Bayi Agricultural University, 2010

[2] Li Weiguo. Monitoring and forecasting of winter wheat yield classification based on TM remote sensing [C]// China remote sensing conference. 2010.

[3] Du Tianhao. Based on the MODIS-NDVI of Henan province winter wheat yield estimation model of [D]. Chongqing: Chongqing University, 2013

[4] Li S, Li M. Yield estimation of winter wheat in early growth periods by vehicle-borne ground-based remotesensing system[J]. Transactions of the Chinese Society of Agricultural Engineering, 2014, 30(3):120-127.

[5] He Zhen, He Junping. NOAA-NDVI of Henan province winter wheat yield estimation by remote sensing [J]. arid land resources and environment, based on the 2013, 27 (5): 46-52.

[6] Maselli F, Chiesi M, Brilli L, et al. Simulation of olive fruit yield in Tuscany through the integration of remote sensing and ground data[J]. Ecological Modelling, 2012, 244(1745):1-12.

[7]Dubovyk O, Menz G, Conrad C, et al. Spatio-temporal analyses of cropland degradation in the irrigatedlowlands of Uzbekistan using remote-sensing and logistic regression modeling[J].Environmental Monitoring & Assessment, 2013, 185(6):4775.

[8] Huismann I, Stiller J, Fröhlich J. Application of Remote Sensors in Mapping Rice Area and Forecasting Its Production: A Review[J]. Sensors, 2015, 15(1):769.

[9] Bouvet A, Toan T L. Use of ENVISAT/ASAR wide-swath data for timely rice fields mapping in the Mekong River Delta[J]. Remote Sensing of Environment, 2011, 115(4):1090-1101

[10] Deng Shubin, Chen Qiujin, Du Huijian,et al.ENVI remote sensing image processing method [M]. Beijing, Xicheng District: Higher Education Press, 2014

[11] Li Fenling. Quantitative estimation of leaf nitrogen hyperspectral data and satellite image in winter wheat in Guanzhong area [D]. Shaanxi City, Xianyang Province, Northwest Agriculture and Forestry University, 2016

[12] ZHANG Shi-zhi, ZHANG Ming-jin, DU Yiping.Study on the Characteristic Screening of Proteomic Mass Spectrometry Data by Chemometrics [J]. Analysis Laboratory, 2012, 31 (10): 106-109.