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Inversion of Canopy Nitrogen Content in Apple Orchard Based on GF-1 Satellite Image

Shujing Cao[1], Xicun Zhu [1,2,*], Jingling Xiong [1], Ruiyang Yu [1], Xueyuan Bai [1],Yuanmao Jiang [3], Dongsheng Gao [3], Guijun Yang[4]

1 College of Resources and Environment, Shandong Agricultural University, Tai'an 271018, China

2 Key Laboratory of Agricultural Ecology and Environment, Shandong Agricultural University, Tai'an 271018, China

3 College of Horticulture Science and Engineering, Shandong Agricultural University, National Apple Engineering and Technology Research Center, Tai'an 271018, China

4 National Engineering Research Center for Information Technology in Agriculture, Beijing 100097, China

[†]Email: zxc@sdau.edu.cn

Abstract

The apple orchard in Qixia City, Yantai City, Shandong Province was used as the research area. The nitrogen content inversion of apple canopy was studied by using the satellite remote sensing images of GF-1. On the basis of GF-1 satellite multispectral image preprocessing, vegetation index was extracted by band math. The nitrogen sensitive vegetation index of apple canopy was selected by correlation analysis of nitrogen content in apple canopy. The best inversion model for the nitrogen content of apple canopy was selected by establishing the regression model of univariate and multivariate factors. The nitrogen content of the canopy of apple orchard in the study area was inverted in space. The results showed that the 6 vegetation indices of RVI, NDVI, EVI, VARI, NPCI and NRI were better correlated with nitrogen content in the vegetation index based on GF-1 satellite multispectral imaging. The best inversion model of nitrogen content in apple canopy layer is the multivariate stepwise regression (MSR) model: N_c = 35.74–41.978*NPCI-10.78*NDVI. The R^2 and RMSE of the model was 0.69 and 1.07. The spatial inversion of nitrogen content in apple orchard canopy was obtained. This study provided theoretical basis and technical support for large-area rapid monitoring of regional fruit tree nutrients.

Keywords: GF-1; Nitrogen Content; Inversion; Apple Tree; Canopy

1 INTRODUCTION

Nitrogen is one of the indispensable nutrients in apple growth and an important material basis for fruit growth. Reasonable application of nitrogen fertilizer is helpful to the growth of fruit trees and the enhancement of photosynthesis. Sufficient nitrogen can promote flowering, fruit-setting and fruit enlargement, and play an important role in regulating the yield and quality of fruit trees[1]. With the development of agricultural remote sensing application research, remote sensing technology has attracted more and more attention because of its new way of obtaining nitrogen in large area, quickly and nondestructive. Using remote sensing images to inversion based on biochemical indicators of crops has become the focus of multi-platform remote sensing precision agriculture information acquisition[2]. GF-1 is a domestic high-resolution satellite with high time resolution and spatial resolution. Its repetition period is 4 days and it has high timeliness. GF-1 satellite is equipped with two 2-meter resolution panchromatic and 8-meter resolution multispectral cameras, which can meet the precise requirements of vegetation nutrient content monitoring and have great potential in crop nutrient research. Domestic scholars have done some research work in the remote sensing monitoring of crop nutrients by using GF-1 satellite data. Huang Rugen et al[3] use GF-1 image data combined with the measured data of typical subtropical crops to construct vegetation index. The estimation model of vegetation index and canopy SPAD is established and the canopies SPAD of typical subtropical crops are estimated well. Li Fenling et al[4] use the spectral response function of GF-1 satellite to resample the high spectral data of winter wheat canopy measured on the ground. The simulated reflectivity of visible and near-infrared bands is obtained and the spectral index is constructed. The spectral index significantly correlated with the nitrogen content of leaves is obtained. The best estimation model of nitrogen content in winter wheat leaves is established and screened. Jia Yuqiu et al [5] use GF-1 and Landsat 8 image data to estimate the maize LAI and find that they have spatial consistency. Wang Lihui et al [6] establish a retrieved corn LAI model by calculating vegetation index based on GF-1 WFV data. Zhu Yunfang et al [7] establish BP neural network model through GF-1 satellite WFV multispectral photographs to estimate the chlorophyll a concentration in Taihu Lake. At present, most of the inversion of nutrient content using domestic satellites in China is concentrated in wheat, corn and other field crops, and there is less research on nutrient content of apple fruit trees. Therefore, this study takes Qixia of Shandong Province as the research area. Nitrogen content inversion of apple canopy layer in the study area is carried out by using GF-1 satellite remote sensing images combined with nitrogen content data of apple canopy layer. The best inversion model of nitrogen content in apple canopy layer based on GF-1 satellite multispectral images is selected. The spatial inversion of nitrogen content in apple canopy in the study area is carried out by using the best model to provide technical support for nutrient monitoring and prediction of apple tree.

2 MATERIALS AND METHODS

2.1 Study Area

The research area is qixia city, yantai city, shandong province. The city is located in the hinterland of jiaodong peninsula, between the northern latitude 37 ° 05 'to 37 ° 32', longitude 120 ° 33 '- 121 ° 15' between. The climate is temperate monsoon climate, annual average temperature 11.3 ℃, annual average rainfall of 754 mm. The average frost-free period is 207 days and the temperature difference between day and night is large in autumn. The soil is mostly brown loam, and the natural environment is very suitable for apple growth. The orchards in this area are large and concentrated, so it is suitable to use remote sensing for large area study.

2.2 Data Sources

1) Canopy Leaf Collection of Apple Trees

The leaf samples were collected on May 24, 2017. They were mainly collected in 20 orchards in the Qixia area, and apple trees with good growth conditions and away from obvious objects (roads, canals, etc.) were selected. In the four directions of the east, west, and north of the apple tree canopy, three mature leaves of similar size and color were taken, totaling 12 leaves. Three fruit trees were collected from each orchard. A total of 59 samples were collected and placed in a ziplock bag. The sealed number was placed in a fresh-keeping box and stored in the laboratory for nitrogen determination. The latitude and longitude coordinates at the sample collection point are recorded synchronously using differential GPS. The sampling point distribution is shown in Figure 1.

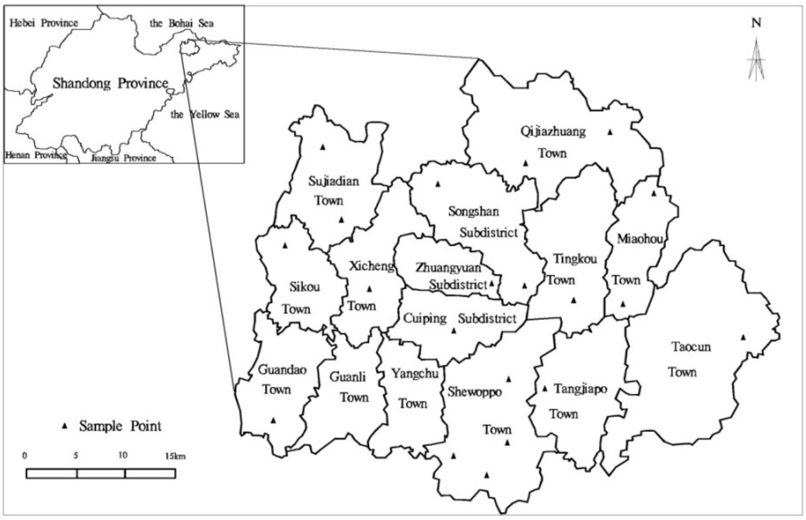


FIG.1 SAMPLING POINT DISTRIBUTION MAP

2) Determination of Nitrogen Content in Apple Canopy Leaves

Wipe the apple leaves with absorbent cotton (remove bordeaux liquor, dust and other factors from the leaves). In the 105℃ oven filming for 30 minutes. And then 80℃ drying to constant weight. The dried leaves were ground into powder with a mortar, mixed evenly and then 0.2g of the dried leaves were taken and put into the decanting tube. H_2SO_4-H_2O_2 was added for decoction, and 100 ml volumetric flask was used for volume determination after the decoction was clarified. After shaking well, the nitrogen content was determined by kjeldahl apparatus. 10 mL(V_2) of 100 mL(V) constant volume boiling liquid was absorbed into the distillation tube. Put another 150 mL tripod bottle in the position of receiving the distillation liquid, and set the time until the machine stops distillation automatically. The flask was removed and titrated on a titration stand with a sulfuric acid standard solution (concentration c) until the solution was mutated from blue to purplish red. Record the volume of the sulfuric acid standard solution V_1 used for titration. Before performing the sample determination, the blank sample is measured (the titration blank is used with a sulfuric acid standard volume of V_0) to correct the error in the reagent and titration. Nitrogen content calculation formula:

$$\omega(N) = c(V_1-V_0)\times 14\times V/V_2 m$$

In the formula, $\omega(N)$ is the mass fraction of total nitrogen in plants (g.kg^{-1}). c is the acid standard solution concentration(mol.L^{-1}). V_1 is the volume of acid standard solution (mL). V_0 is the acid standard solution (mL) used to titrate the blank. 14 is the molar mass of N (g.moL^{-1}). V is the volume of the cooking liquid (mL). V_2 is the volume of the liquid to be measured by suction; m is the mass of the sample to be weighed.

The nitrogen content of apple canopy leaves was arranged in small to large order, and the modeling set and verification set were extracted by 2:1 equidistant sampling method. Among the 59 valid samples, 40 are training samples and 19 are test samples. The statistical results of nitrogen content characteristics in leaves of apple canopy obtained in the experiment are shown in Table 1.

TABLE 1 CHARACTERISTICS OF TOTAL NITROGEN CONTENT OF SAMPLE STATISTIC

Sample	Number	Max (g·kg^{-1})	Min (g·kg^{-1})	Mean (g·kg^{-1})	Standard Deviation	Variance	Coefficient of Variation
Total	59	36.73	23.27	29.97	2.77	7.68	0.09
Modeling	40	36.73	23.27	29.92	3.06	9.34	0.10
Test	19	33.00	23.49	30.28	1.71	2.93	0.06

3) GF-1 Satellite Image Data Acquisition and Processing

The GF-1 satellite multi-spectral image data has a total of 4 scenes, and the acquisition time is May 24, 2017. The relevant parameters are shown in Table 2.

TABLE 2 GF-1 MULTISPECTRAL SATELLITE IMAGE PARAMETERS

Camera	Spectral Range (μm)	Spatial resolution (m)	Width (km)	Side swing ability	Revisiting time (day)
Multispectal camera	0.45～0.52 0.52～0.59 0.63～0.69 0.77～0.89	8	60 (Two camera combinations)	±35°	4

Multispectral images were radiometrically calibrated using ENVI 5.3 software, FLAASH atmospheric correction, orthorectification of images, and image mosaic. According to the administrative vector division boundary vector file of Qixia City, Shandong Province, the image of the GF-1 multispectral image was obtained, as shown in Figure 2.

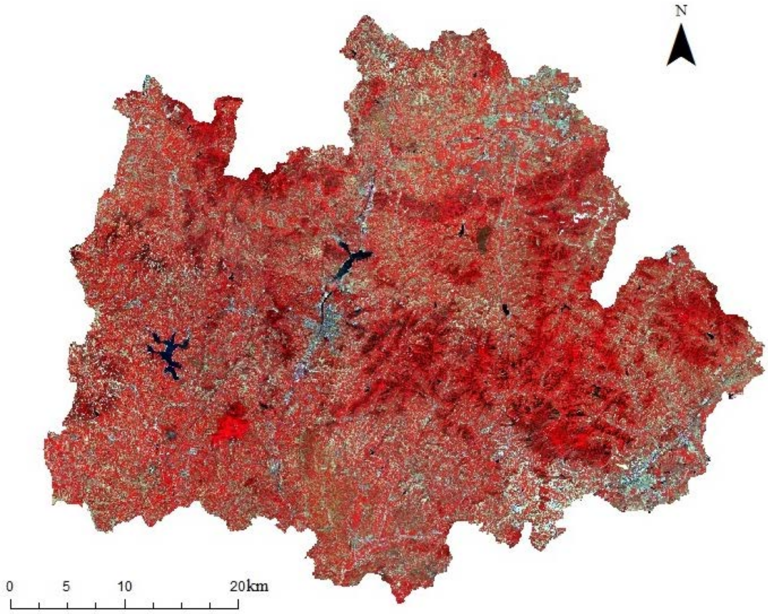


FIG.2 MULTISPECTRAL IMAGE OF GF-1 SATELLITE IN QIXIA CITY

2.3 Data Analysis and Method

The GPS point coordinates obtained in the field measurement in the study area are positioned on the GF-1 image, and the error is controlled within one pixel. According to the vegetation index calculation formula in Table 3, the selection and the nitrogen content were significantly correlated with the nitrogen content at the 0.01 level, and the vegetation index with the correlation coefficient higher than 0.5 was used for the estimation of the canopy nitrogen content. A single-variable linear model is used, including a unary linear model and a two-time polynomial model, and a multivariate regression model, including MLR (Multiple linear regression), MSR(Multivariate stepwise regression), and PLSR(Partial least squares regression). Through the comparative analysis of different models, the accuracy of the model was tested, and the best inversion model of nitrogen content in apple canopy leaves was obtained. Based on the best model, the spatial inversion of nitrogen content in apple canopy was studied.

TABLE 3 VEGETATION INDICES AND ITS EXPRESSION

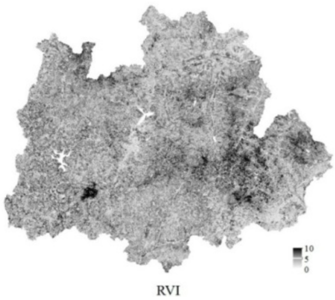
Number	**Spectral parameters**	**Algorithm formula**	**Reference**
1	RVI	*NIR*/*R*	Jordan et al.(1969)[8]
2	DVI	*NIR*-*R*	Richardson.(1977)[9]
3	NDVI	(*NIR*-*R*)/(*NIR*+*R*)	Rouse et al.(1974)[10]
4	GNDVI	(*NIR*-*G*)/(*NIR*+*G*)	Gitelson et al.(1996)[11]
5	EVI	2.5(*NIR*-*R*)/(*NIR*+6*R*-7.5*B*+1)	Huete et al.(1995)[12]
6	VARI	(*G*-*R*)/(*G*+*R*-*B*)	Gitelson et al.(2002)[13]
7	GRVI	(*NIR*/*G*)-1	Gitelson et al.(1996)[14]
8	NPCI	(*R*-*B*)/(*R*+*B*)	Penuelas et al.(1994)[15]
9	SIPI	(*NIR*-*B*)/(*NIR*+*B*)	Penuelas et al.(1995)[16]
10	NRI	(*G*-*R*)/(*G*+*R*)	Schleicher et al.(2001)[17]
11	SAVI	1.5(*NIR*-*R*)/(*NIR*+6*R*-7.5*B*+0.5)	Huete et al.(1988)[18]
12	OSAVI	1.16(*NIR*-*R*)/(0.16+*NIR*+*R*)	Rondeaux et al.(1996)[19]

Note: *B*, *G*, *R*, and *NIR* are the reflectance of the blue, green, red, and near-infrared bands of the image.

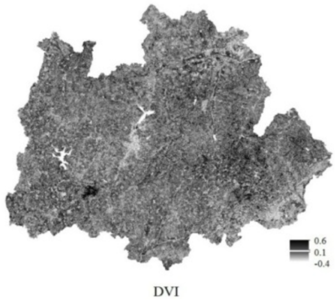
3 RESULTS AND ANALYSIS

3.1 Vegetation Index Extraction

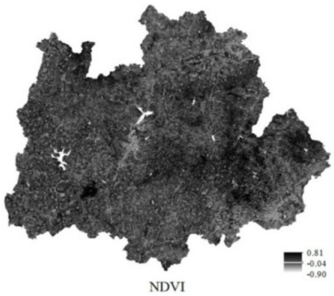
According to the vegetation index formula of Table 3, the calculation of vegetation index in the study area was carried out by band calculation. The vegetation index is extracted using GPS coordinates obtained in the field, as shown in Figure 3.



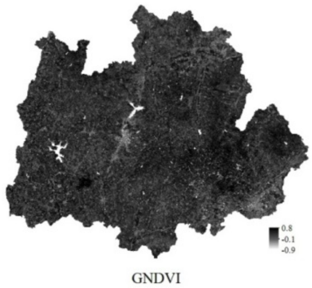
A: RVI



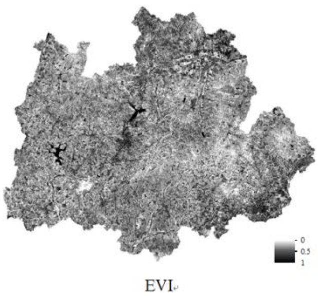
B: DVI



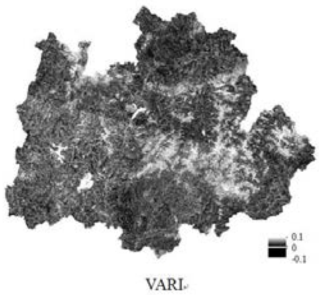
C： NDVI



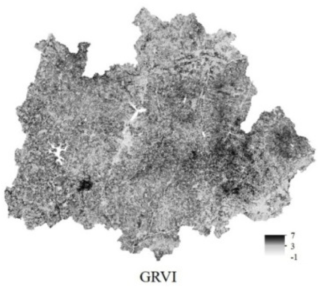
D: GNDVI



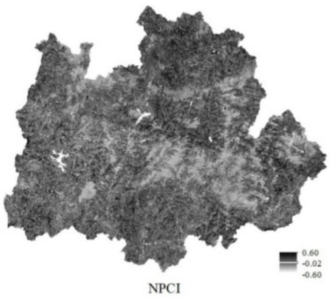
E： EVI



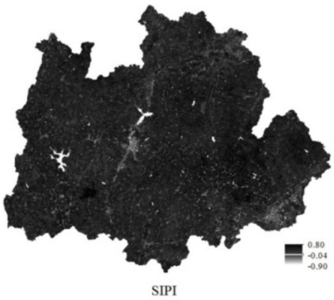
F： VARI



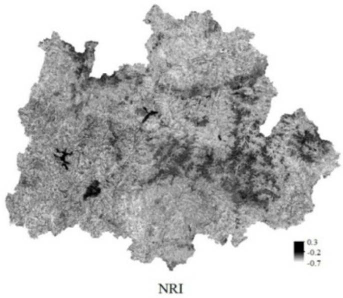
G: GRVI



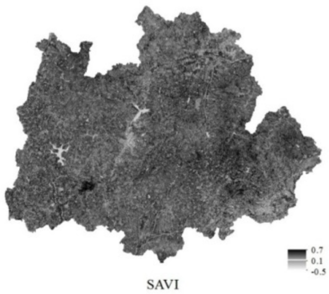
H： NPCI



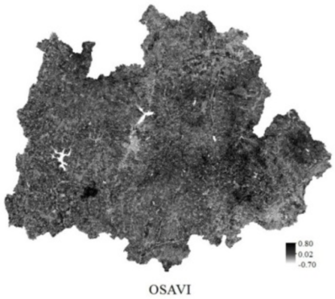
I : SIPI



J : NRI



K : SAVI



L : OSAVI

FIG.3 Extraction of 12 vegetation index based on GF-1 image

3.2 Correlation Analysis between Vegetation Index and Nitrogen Content

Correlation analysis was performed using the 12 planting index in Table 3 and the nitrogen content of the apple tree canopy. The correlation coefficients of RVI, NDVI, EVI, VARI, NPCI and NRI with leaf nitrogen content were 0.64, 0.57, 0.58, -0.61, -0.75, and 0.73, respectively. All passed the extremely significant test of p less than 0.01 level. Among them, VARI and NPCI were negatively correlated with leaf nitrogen content. Because with the increase of nitrogen content in leaves, the ability of leaves to photosynthesize is enhanced. The absorption of red and blue light increases. The reflectivity of the near-infrared band increases.

TABLE 4 CORRELATION COEFFICIENT BETWEEN VEGETATION INDEX AND NITROGEN CONTENT

Vegetation index	**Correlation coefficient**	**Vegetation index**	**Correlation coefficient**
RVI	0.64**	GRVI	0.48**
DVI	0.42**	NPCI	-0.75**
NDVI	0.57**	SIPI	0.32*
GNDVI	0.42**	NRI	0.73**
EVI	0.58**	SAVI	0.51**
VARI	-0.61**	OSAVI	0.54**

Note: ** indicates extremely significant at the 0.01 level, and * indicates significant at the 0.05 level.

3.3 Inversion of Nitrogen Content in Apple Canopy Layer Based on Vegetation Index

In order to establish an inversion model of nitrogen content in Apple canopy based on GF-1 satellite images. Single-variable regression model and multivariate regression model were established by combining the selected vegetation index RVI, NDVI, EVI, VARI, NPCI and NRI.

1) Establishment and Test of Single Variable Regression Model

The single variable regression model of vegetation index and canopy nitrogen content was established by using the nitrogen content of 40 modeling samples and the vegetation index of RVI, NDVI, EVI, VARI, NPCI and NRI respectively. Based on the maximum principle of R^2, a model with remarkable modeling effect is selected. The Nitrogen content function curve of vegetation index is shown in Figure 4.

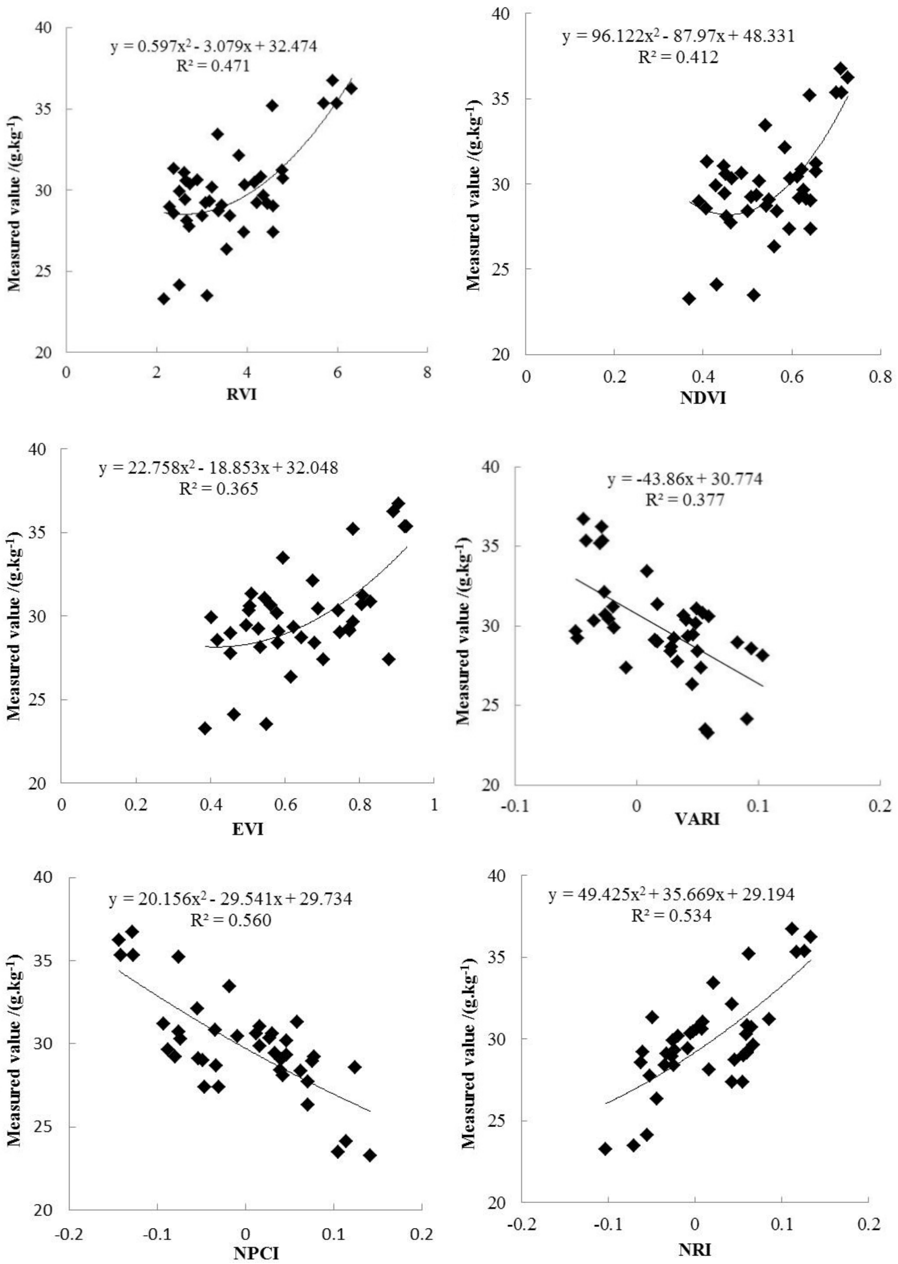


FIG.4 LEAF NITROGEN CONTENT FUNCTION CURVE OF VEGETATION INDEX

It can be seen from Fig. 4 that the best model for establishing the nitrogen content of RVI, NDVI, EVI, VARI, NPCI and NRI and canopy is the quadratic polynomial model. There is a linear correlation between VARI and canopy nitrogen content. It can be found that the nitrogen content model has a good effect because of the extremely significant correlation between vegetation index and nitrogen content. In the model in which the same planting index is used to establish different models, the effect of the quadratic polynomial model is better than that of the simple linear model. Among them, NPCI and NRI have the highest correlation with canopy nitrogen content. Therefore, the univariate linear model established by NPCI and NRI and canopy nitrogen content is also the best. R^2 is 0.56 and 0.53, respectively.

The accuracy of the model based on a single variable was verified using 19 test samples. The R^2 and RMSE indicators were used to test the ability and accuracy of different models for canopy nitrogen content. In general, the higher the R^2, the smaller the RMSE, and the better the accuracy and stability of the model. Based on this, the best model for estimating nitrogen content by single vegetation index was selected. The predicted values of the model and the test sample fitting results are shown in Figure 5.

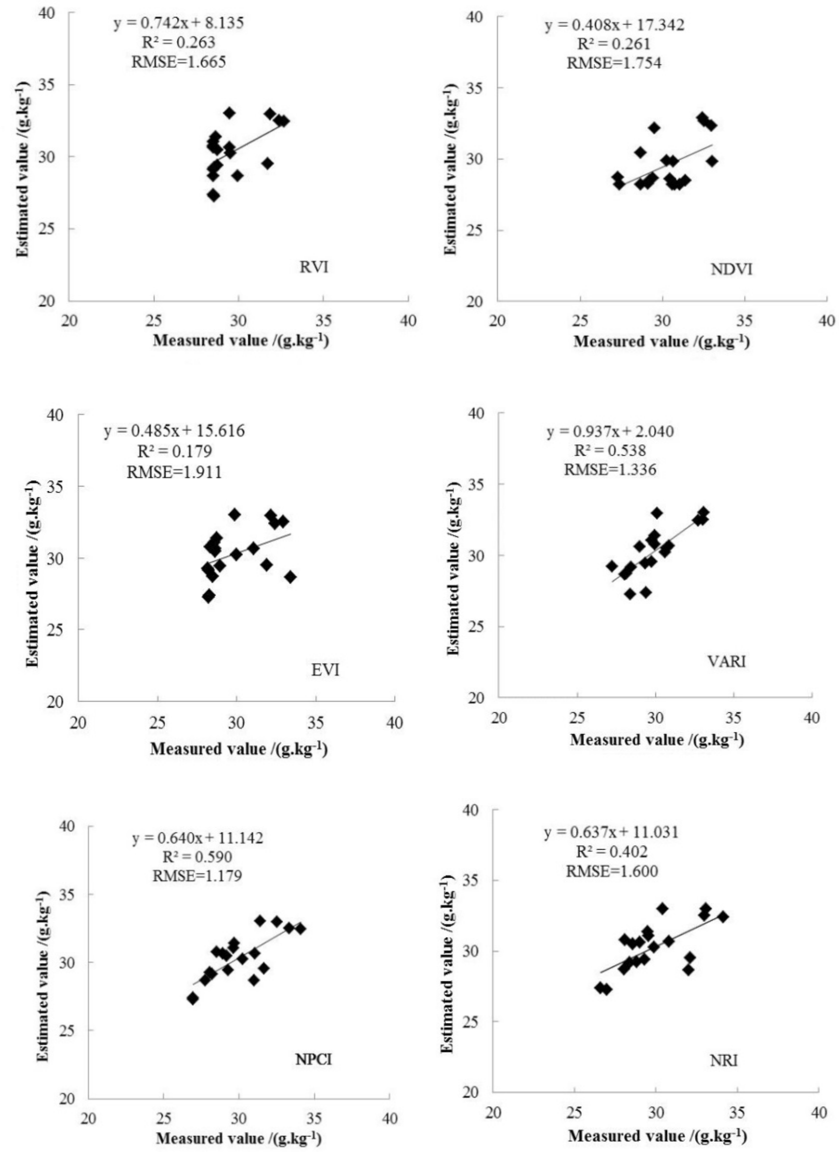


FIG.5 FITTING THE MEASURED AND ESTIMATED VALUES OF LEAF NITROGEN CONTENT BASED ON THE VALIDATION SET

It can be seen from Figure 5 that the model validation results of the three vegetation indices and nitrogen content of VARI, NPCI and NRI are better. The verification indicators have met the inspection requirements. R^2 were 0.54; 0.59 and 0.40.RMSE were 1.34, 1.18 and 1.60. Among them, NPCI has the highest R^2 and the smallest RMSE, indicating that the nitrogen content inversion model established by NPCI has the highest precision and the highest stability, and can better invert the nitrogen content. Since the calculation formulas of NDVI, RVI and EVI have near-infrared or red-light bands, these bands are sensitive to the chlorophyll content of apple canopy, so the estimated nitrogen content in the model is more concentrated. R^2 is only about 0.2, and the accuracy is relatively low. In summary, the best model for univariate canopy nitrogen content is based on the quadratic polynomial model established by NPCI. The model formula is: $Nc = 20.16*NPCI^2 – 29.54*NPCI + 29.73$. R^2 is 0.59 and RMSE is 1.18. It has the highest precision and stability and can better invert the nitrogen content.

2) Establishment and Test of Multivariate Regression Model

Six vegetation indices including RVI, NDVI, EVI, VARI, NPCI, NRI (X_1、X_2、X_3、X_4、X_5、X_6) were used as independent variables. The nitrogen content is the dependent variable. Considering the mathematical relationship between vegetation indices, a multiple linear regression model of apple canopy nitrogen content with two or more vegetation indices combined as independent variables, including MLR, MSR, PLSR. The regression equation established by the model, R^2 is shown in Table 5.

TABLE 5 MULTIVARIATE LINEAR REGRESSION INVERSION MODEL FOR NITROGEN CONTENT

Model	**Regression equation**	R^2
MLR	$y = 42.05 - 187.01*X_5 - 153.74*X_6 + 78.08*X_4 + 4.23*X_1 - 8.03*X_3 - 40.14*X_2$	0.66
MSR	$y = 35.74 - 41.98*X_5 - 10.78*X_2$	0.57
PLSR	$y = 25.44 - 5.74*X_5 + 7.26*X_6 - 8.45*X_4 + 0.34*X_1 + 2.18*X_3 + 3.40*X_2$	0.49

Note: y is the nitrogen content of leaves. X_1, X_2, X_3, X_4, X_5, X_6 are vegetation index RVI, NDVI, EVI, VARI, NPCI, NRI.

It can be seen from Table 5 that the established MLR, MSR, PLSR models all pass the significance test. The linear regression model of nitrogen content and the stepwise regression model using vegetation index combination have the best effect. The model equations are: Nc = 42.05 - 187.01*NPCI - 153.74*NRI + 78.08*VARI + 4.23*RVI - 8.03*EVI - 40.14*NDVI and Nc = 35.74 - 41.98*NPCI - 10.78*NDVI. R^2 is 0.66 and 0.57 respectively. Compared with the use of a single variable to establish a linear model, the regression model of nitrogen content established by using multiple vegetation index combinations as the dependent variable is better, which contributes to the improvement of model accuracy and feasibility.

It can be seen from Table 5 that the three vegetation indices RVI, NDVI and NPCI play an important role in the accuracy of model establishment. When modeling a single variable, the univariate model with RVI and NDVI as dependent variables is less effective. The effect of the model established after combination with other vegetation indices is improved.

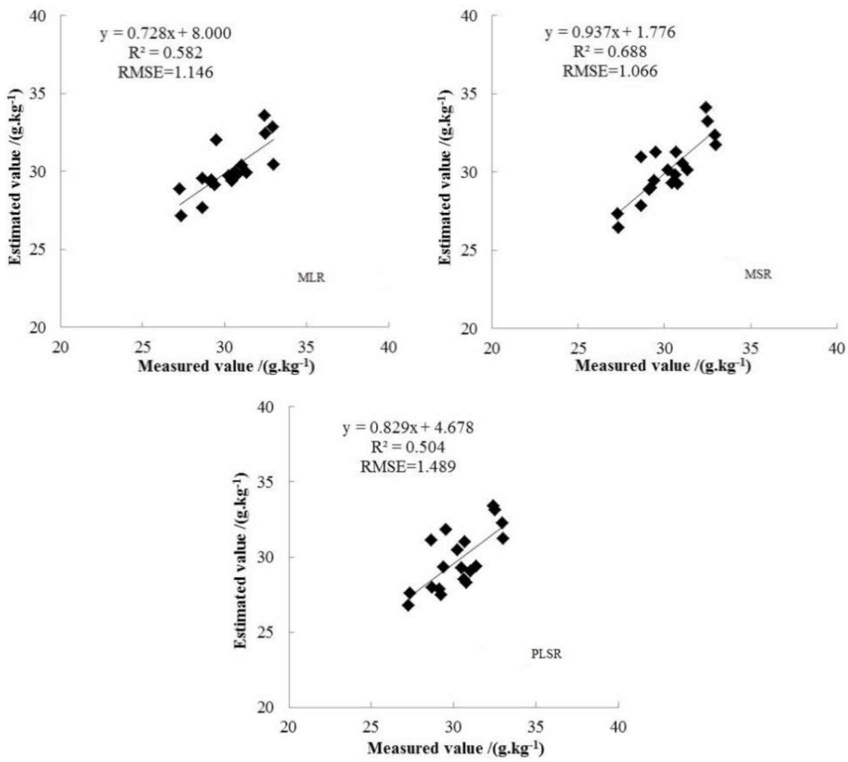


FIG.6 MEASURED VALUE AND ESTIMATED VALUE DISTRIBUTION MAP BASED ON VERIFICATION SET

The model accuracy of different vegetation index variables was tested using 19 validation samples. As shown in

Figure 6, both of them passed the significance test of p less than 0.01.

The R^2 and RMSE of the MLR test are 0.58 and 1.15. The R^2 and RMSE of the MSR test are 0.69 and 1.07. The R^2 and RMSE of the PLSR test are 0.50 and 1.49. Among them, MSR has the best verification effect, and the model has the highest accuracy and stability. Therefore, the linear optimal inversion model for canopy nitrogen content based on multivariate is based on a multivariate stepwise regression model established using NPCI and NDVI. The regression equation is : Nc = 35.74 - 41.98*NPCI - 10.78*NDVI.

By comparing the univariate regression model with the multivariate regression model, the optimal estimation model of canopy nitrogen content in apple leaves based on GF-1 satellite imagery is a multivariate stepwise regression model: Nc = 35.74 - 41.98 * NPCI - 10.78 * NDVI .

3.4 Spatial Inversion of Canopy Nitrogen Content in Apple Orchard in Study Area

The GF-1 multispectral image correlation bands were selected for NPCI and NDVI index calculations. According to the best inversion model of apple tree canopy nitrogen content, namely the multivariate stepwise regression model established by NDVI and NPCI (Nc = 35.74 - 41.98*NPCI - 10.78*NDVI). The leaf nitrogen content was estimated. The apple orchard area in the study area was extracted as a mask, and the distribution of nitrogen content in the canopy of the apple tree in the study area was obtained, as shown in Figure 7.

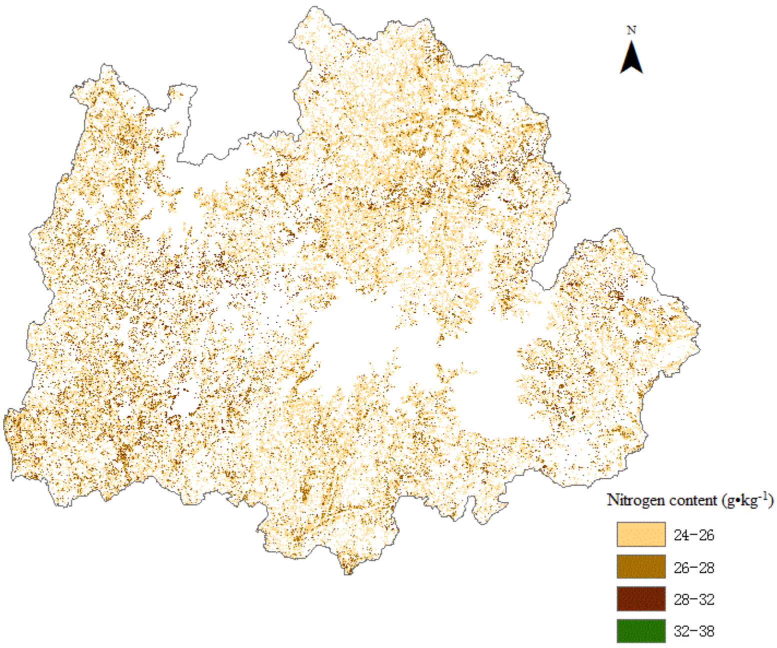


FIG.7 SPATIAL DISTRIBUTION OF NITROGEN CONTENT IN APPLE CANOPY IN THE STUDY AREA

The nitrogen content in the canopy of the apple orchard in the study area was mainly concentrated between 24 and 32 $g{\bullet}kg^{-1}$, accounting for more than 90%. The southwestern and northeast apple orchards in the study area are densely distributed and have high nitrogen content, mainly concentrated in 26 - 32 $g{\bullet}kg^{-1}$, which is consistent with the distribution of nitrogen content obtained by field sampling.

4 CONCLUSION

RVI, NDVI, EVI, VARI, NPCI and NRI extracted from GF-1 multi-spectral images had a high correlation with nitrogen content in apple canopy, and the correlation coefficients were greater than 0.5. The best model for nitrogen content based on univariate is based on the quadratic polynomial model established by NPCI. The model formula is: Nc= 20.16*NPCI2 - 29.54*NPCI + 29.73. R^2 of model test is 0.59, and RMSE is 1.18. The multivariate stepwise regression model based on NPCI and NDVI was Nc= 35.74 - 41.98*NPCI - 10.78*NDVI. The model test had R^2 of 0.69 and RMSE of 1.07. Compared with the univariate model, the canopy nitrogen content inversion model based on multivariate is better. The optimal model was used to spatially invert the nitrogen content of apple canopy in the orchard. This study provided technical support for the growth and nutrient status of apple trees in the orchard of Qixia City.

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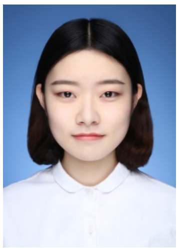
AUTHORS



Shujing Cao (1994-). She is a graduate student of land resources management in Shandong Agricultural University. Her research direction is agricultural remote sensing.

Xicun Zhu (1970-). He is a professor at the College of Resources and Environment at Shandong Agricultural University. His research direction is the application of agricultural remote sensing and remote sensing technology.