

Remote Sensing Inversion of Nitrogen Nutrition Status of Apple Tree Leaves during Stopping Period of Spring Shoots

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Abstract

The nutrient inversion model of apple leaves was established by spectral analysis technology to provide technical support for the fine management of apple trees. In Shuangquan Town, Changqing District, Jinan City, Shandong Province, the Fuji apple trees with stopping period of spring shoots were taken as research objects. The spectral reflectance and nitrogen content of apple leaves were measured by ASD Field Spec 4 portable ground object spectrometer. Analyzed the correlation between leaf nitrogen content and spectral reflectance. The sensitive wavelengths with high correlation coefficient were select by fractional differential algorithm, and the optimal vegetation index was constructed and screened out. Partial Least Square Regression (PLSR), Support Vector Machine (SVM) and Random Forests (RF) method were used to construct an inversion model of leaf nitrogen content. The results show that the RF model based on fractional differential second-order treatment is the best inversion model for the nitrogen content of leaves during stopping period of spring shoots. The modeling accuracy determination coefficient R^2 reached 0.891, RMSE was 0.0841, and RPD was 2.1396. The determination coefficient R^2 of the fitting results of the verification set was 0.617, RMSE was 0.1251, and RPD was 1.7105. The inversion model established by RF method is effective in monitoring the nitrogen content in apple leaves, which provides a theoretical basis for monitoring the growth of apple by hyperspectral technology.

Keywords: Apple Tree; Stopping Period of Spring Shoots; Nitrogen Nutrition; Remote Sensing Inversion

1 INTRODUCTION

Nitrogen is an indispensable nutrient element in plant growth and development. Traditional methods for measuring nitrogen content in plants are time-consuming, laborious and destructive. In recent years, the application of hyperspectral remote sensing technology to quickly monitor the nitrogen status of apple trees and make reasonable management measures for apple trees to realize accurate fertilization has become a research hotspot in modern agriculture. In recent years, in crop nitrogen nutrition monitoring based on remote sensing, there have been increasing reports from scholars at home and abroad who used remote sensing to invert nitrogen content (concentration) or nitrogen accumulation (density) to determine the nitrogen nutrient status of crops. Hyperspectral technology has been successfully applied to nondestructive testing of nitrogen content in crop leaves. Darvishzadeh et al.³ based on the NDVI formula, a similar and inspiring NDVI index was developed using hyperspectral data. The performance of this index in crop variable evaluation (such as leaf area index) was significant. Its ability and applicability in retrieving other variables such as nitrogen and chlorophyll are worth studying. Koppe et al.⁴ for the study of winter wheat at different growth stages, three different prediction models were used to calculate the traditional vegetation index from broadband and narrowband, and the normalized ratio index (NRI) from all possible combinations of two bands between

400-2500 nm. The results showed that the triangle vegetation index (TVI) performed best in the vegetation index. The research on diagnosis of vegetation nitrogen mainly focuses on field crops, good estimation results were obtained in wheat^{5,6}, cotton^{7,8}, rice⁹, soybean^{10,11}, beet¹², corn¹³ and other crops. In apple nutrition diagnosis, Xing et al.¹⁴ taking Fuji apple as an example, leaf information was collected between stopping period of spring shoots and stopping period of autumn shoots, using spectrum analysis method to estimate nitrogen content, The results showed that the correlation between the nitrogen content in leaves and the first-order differential spectrum with wavelength interval of 5 nm was the strongest. The linear trend of the nitrogen content estimation model established on this basis is good, and the correlation coefficient R^2 is above 0.8. Zhu et al.¹⁵ studied the apple leaves in stopping period of spring shoots and stopping period of autumn shoots, The hyperspectral characteristics of different leaf positions, different leaf moisture contents and different apple varieties were analyzed, , which provided a theoretical basis for apple nutrition monitoring.

The atopping period of spring shoots is the key period of the nutrition transformation of apple trees. Strengthening fertilization management in this period can promote the differentiation of flower buds and the growth of young fruit. Based on shuangquan town, changqing district, jinan city, shandong province, this paper used hyperspectral technology to estimate the nitrogen content of apple trees in the stopping period of spring shoots, which is of great significance to obtain the nutritional information of apple trees quickly and accurately, so as to improve the yield and quality of apple trees.

2 MATERIALS AND METHODS

2.1 Survey of Research Area

The study area is Shuangquan Town (116 42 ' -116 71 ' E, 36 20 ' -36 34 ' N) in Jinan City, Shandong Province.

2.2 Experimental Data Acquisition

1) Sample Collection

The collection time is mid-to-late June 2019. Representative Fuji apple trees were randomly selected from the orchards in the research area and their center coordinates were measured by GPS. Six leaves were collected from the upper, middle and lower parts of the Yin and Yang sides of each tree, and 18 leaves were collected from the Yang and negative sides of each tree.

2) Determination of Leaf Spectral Data and Nitrogen Content

The instrument used for the determination of spectral data of leaves was the portable ASD Field Spec 4 ground object spectrometer. Each leaf was measured five times, and the arithmetic mean value was used as the spectral data of the corresponding leaf. The nitrogen content in apple leaves was determined by K9860.

2.3 Spectral Data Processing

The methods to improve the data correlation mainly include digital transformation of spectral data, fractional differentiation and so on¹⁶. In this paper, savitzky-golay convolution smoothing method is used for data processing, and fractional differential algorithm is used to improve the correlation of spectral data. Fractional-order derivative (FOD) is a theory of arbitrary order differential, which is unified with integer order differential and generalization of integer order differential. There are about three commonly used definitions of FOD: Riemann-Liouville, Grunwald-Letnikov, Caputo fractional derivative¹⁷. In this paper, the Grunwald-Letnikov differential definition form is used for fractional differential processing of the original spectral data.

$$d^{\alpha} f(x) = \lim_{h \rightarrow 0} \frac{1}{h^{\alpha}} \sum_{m=0}^{\frac{t-a}{h}} (-1)^m \frac{\Gamma(\alpha+1)}{m! \Gamma(\alpha-m+1)} f(x - mh) \quad (1)$$

Where, α is the differential order; h is the differential step length; a and t are the upper and lower limits of differentiation; The Gamma function $\Gamma(z) = \int_0^{\infty} e^{-u} u^{z-1} du = (z-1)!$.

If $h=1$, and differentiate the upper and lower bounds, that is, the differential data length $n=[t-a]$, then formula (1) can

be used to deduce the difference value expression (2) of $f(x)$ fractional differential:

$$d^\alpha f(x) \approx f(x) - \alpha f(x-1) + \frac{\alpha(\alpha-1)}{2} f(x-2) - \frac{\alpha(\alpha-1)(\alpha-2)}{3!} f(x-3) + \dots + (-1)^n \frac{\Gamma(\alpha+1)}{n! \Gamma(\alpha-n+1)} f(x-n) \quad (2)$$

Pre-processing of data according to equation (2), 0~2 order differential processing is carried out on the original spectrum in the software, with order interval of 0.5, and 5 kinds of original and differential spectral data are finally obtained. Order 0 is the original spectrum without differential processing.

2.4 Vegetation Index

Vegetation index is an index that combines and calculates the data detected by satellites in different bands to enhance certain characteristics of vegetation and reflect the growth status of plants¹⁸. According to previous experience, the following vegetation indexes were selected in this study to facilitate the follow-up inversion of nitrogen content in apple tree leaves. As shown in table 1.

TABLE 1 CALCULATION FORMULA OF HYPERSPECTRAL VEGETATION INDEX

Vegetation Index	The formula
Normalized Difference Vegetation Index (NDVI)	$(R_{NIR} - R_R)/(R_{NIR} + R_R)$
Enhanced Vegetation Index (EVI)	$2.5 \times (R_{NIR} - R_R)/(1 + R_{NIR} + 6 \times R_R - 7.5 \times R_B)$
Normalized Difference Vegetation Index (RDVI)	$(R_{NIR} - R_R)/\sqrt{R_{NIR} + R_R}$
Soil-Adjusted Vegetation Index (SAVI)	$(R_{NIR} - R_R)/(R_{NIR} + R_R + 0.5) \times 1.5$
Nitrogen Response Index(NRI)	$(R_G - R_R)/(R_G + R_R)$

2.5 Inversion Model and Inspection

In this study the nitrogen content in apple tree leaves was taken as the dependent variable, the spectral characteristic parameters of the blade reflectance were independent variables. The inversion model of nitrogen content in apple tree leaves was established. The modeling methods include PLSR, SVM and RF. The inversion model was verified by the determination coefficient (R^2), the root mean square error (RMSE) and the ratio of relative prediction error (RPD).

3 RESULTS AND ANALYSIS

3.1 Hyperspectral Analysis of Nitrogen Content in Apple Tree Leaves

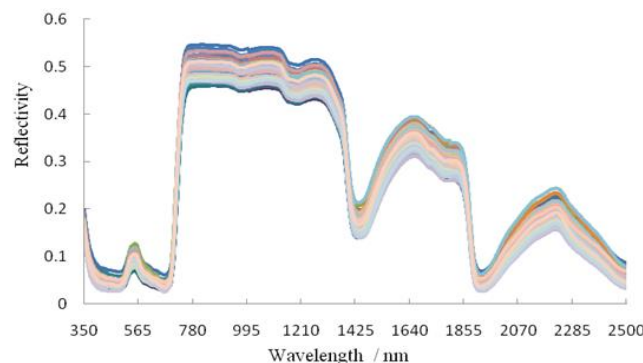


FIGURE 1 SPECTRAL CURVES OF APPLE TREELEAVES

Fig. 1 is a hyperspectral reflectance curve of apple tree leaves. In the range of red light band (610-690 nm), the spectral reflectance is low and tends to decline due to the absorption of red light by chlorophyll in leaves. From the lowest spectral reflectance of the red band to the near-infrared band with higher spectral reflectance, it is the transition band of chlorophyll from the strong absorption of the red band to the high-reflection platform formed by multiple scattering in the near-infrared band. This band range is called "red edge". Spectral reflectance increases rapidly in the red-rimmed band (690-770 nm). In the near-infrared band (770-1100 nm), spectral reflectance reaches a relatively high reflection platform region. The valley value appeared at 1450 nm and 1910 nm, and the peak value appeared at 1680 nm and 2200 nm.

3.2 Selection of Characteristic Parameters of Nitrogen Content in Leaves

Spectral reflectance data obtained after S-G smoothing of the original spectrum and elimination of abnormal data. The original data were transformed into fractional derivative of order 0-2.

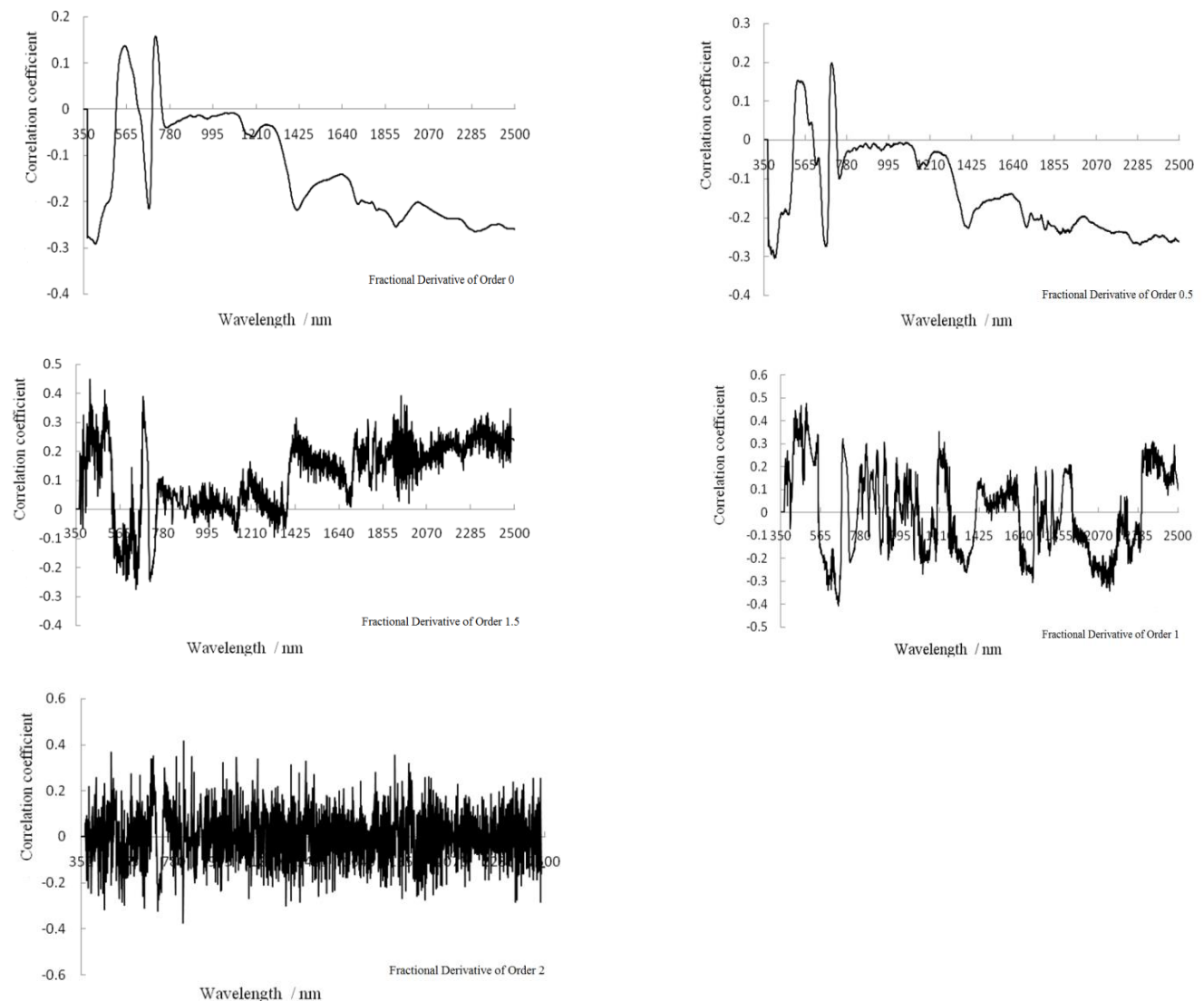


FIGURE 2 CORRELATION COEFFICIENT DIAGRAM OF NITROGEN CONTENT IN LEAVES WITH DIFFERENT TRANSFORMATION FORMS DURING SPRING TIP STOPPING PERIOD

Fig. 2 is the correlation coefficient diagram between different transformation forms and nitrogen content in leaves in the spring tip stopping period. The original spectral reflectance and leaf nitrogen content was strongest at 410 nm, reaching -0.2924. The correlation of the fractional derivative order 0.5 was the strongest at 402 nm, reaching -0.3055,

and the correlation coefficient was slightly improved. The fractional derivative of order 1 was strongest at 458 nm, reaching 0.4737, which was much higher than the original reflectivity correlation coefficient. The correlation of fractional derivative order 1.5 was strongest at 421 nm, reaching 0.4472; the correlation of fractional derivative order 2 was strongest at 827 nm, reaching 0.4149, and the correlation coefficient was the highest compared with other variation forms. Compared with the other five transformation forms, the fractional derivative order 1 transformation has better effect on improving the correlation coefficient. Select the highest 10 sensitive wavelengths from each conversion form, as shown in Table 2:

TABLE 2 SENSITIVE WAVELENGTHS SELECTED UNDER DIFFERENT TRANSFORMATIONS

Transformations	Wavelengths
Fractional differentiation of order 0	386、390、395、407、400、410、412、418、420、421
Fractional differentiation of order 0.5	386、387、394、399、400、402、403、409、411、412
Fractional differentiation of order 1	429、452、457、458、484、486、487、488、490、492
Fractional differentiation of order 1.5	421、427、428、492、498、680、682、685、1943、1960
Fractional differentiation of order 2	492、676、682、685、792、824、827、863、1071、1805

The 10 sensitive wavelengths with the highest correlation coefficients were selected from table 2, which were 421 nm, 458 nm, 488 nm, 628 nm, 680 nm, 827 nm, 1071 nm, 1805 nm, 1943 nm, and 1960 nm, respectively. The selected sensitive wavelengths were used to construct the spectral parameters by using the indexes of NDVI, EVI, RDVI, SAVI and NRI, and the correlation analysis was conducted with the nitrogen content in the leaves. Finally, spectral parameters with higher correlation coefficients were selected: $NDVI_{(628,1805)}$, $NDVI_{(628,1071)}$, $NDVI_{(628,1943)}$, $NRI_{(458,628)}$, $EVI_{(628,1943)}$, $SAVI_{(628,1805)}$, $RDVI_{(628,1805)}$, $RDVI_{(628,1943)}$, $SAVI_{(628,1943)}$, $SAVI_{(628,1071)}$. The selected spectral parameters were used to construct the model.

3.3 Establishment and Test of Hyperspectral Estimation Model for Leaves Nitrogen Content

The selected spectral parameters $NDVI_{(628,1805)}$, $NDVI_{(628,1071)}$, $NDVI_{(628,1943)}$, $NRI_{(458,628)}$, $EVI_{(628,1943)}$, $SAVI_{(628,1805)}$, $RDVI_{(628,1805)}$, $RDVI_{(628,1943)}$, $SAVI_{(628,1943)}$, $SAVI_{(628,1071)}$ were constructed by partial least squares, support vector machines, and random forest, respectively. The results are shown in table 3:

TABLE3 MODEL ACCURACY UNDER DIFFERENT PROCESSING METHODS

	Accuracy evaluation	PLSR	SVM	RF
Fractional differentiation of order 0	R ²	0.406	0.563	0.871
	RMSE	0.2712	0.1254	0.0905
	RPD	1.2782	1.4353	1.9901
Fractional differentiation of order 0.5	R ²	0.408	0.468	0.798
	RMSE	0.2822	0.1330	0.0947
	RPD	1.1861	1.3531	1.9011
Fractional differentiation of order 1	R ²	0.433	0.540	0.835
	RMSE	0.2682	0.1238	0.0899
	RPD	1.2927	1.4546	2.0019

Fractional differentiation of order 1.5	R^2	0.410	0.508	0.809
	RMSE	0.2828	0.1456	0.1270
	RPD	1.2258	1.2368	1.4173
Fractional differentiation of order 2	R^2	0.638	0.623	0.891
	RMSE	0.2126	0.1126	0.0841
	RPD	1.6302	1.5986	2.1396

From table 3, we can see that the estimation accuracy of PLSR and SVM are relatively low. The accuracy verification R^2 of PLSR is about 0.4. SVM accuracy verification R^2 is about 0.5; The accuracy verification results of the RF were the best, with R^2 above 0.7. PLSR is more accurate than other processing methods under the basic treatment of fractional differential order 2. Its R^2 reaches 0.638, RMSE is 0.2126 and RPD is 1.6302. The accuracy of SVM is higher than that of other processing methods under the basic treatment of fractional differentiation order 2. Its R^2 reaches 0.623, RMSE is 0.1126 and RPD is 1.5986. The decision coefficient R^2 of RF reached 0.891, RMSE was 0.0841, and RPD was 2.1396 under the basic treatment of fractional derivative order 2. Therefore, RF works best under the basic treatment of fractional differentiation of order 2.

According to the RF model shown in table 3, the accuracy is the highest under the basic treatment of fractional differentiation of order 2 compared with other treatment methods. The samples were divided into training set and verification set by isometric sampling method, and the selected characteristic parameters were used to establish the model. The fitting results showed that the determination coefficient R^2 was 0.891, RMSE was 0.0841, and RPD was 2.1396. The determination coefficient R^2 of the fitting results of the verification set was 0.617, RMSE was 0.1251, and RPD was 1.7105. As shown in Fig 3:

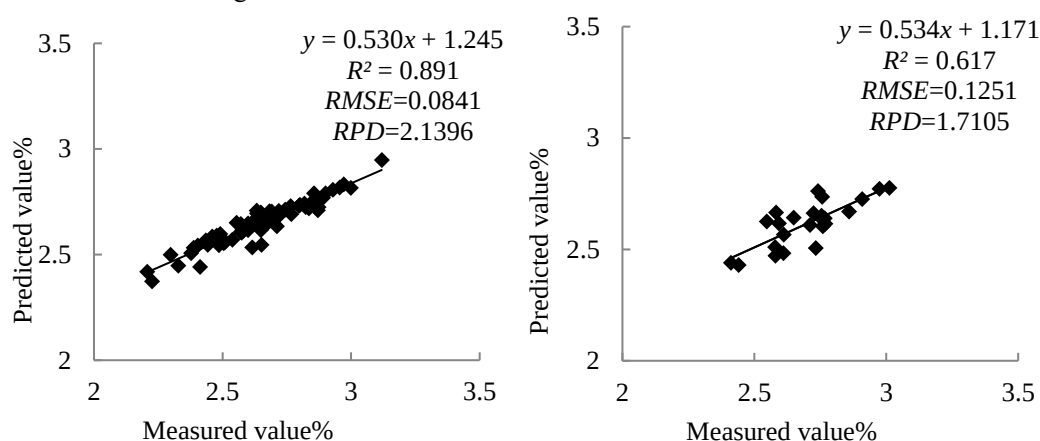


FIGURE 3 SCATTER PLOT OF MEASURED AND PREDICTED NITROGEN CONTENT BASED ON RANDOM FOREST MODEL

CONCLUSION

In this paper, the content of nitrogen in apple trees leaves and spectral characteristics of apple tree leaves during the spring tip stopping period were studied. The fractional differential data transformation was used to extract the sensitive bands and characteristic parameters of nitrogen content in apple leaves at different phenological stages. An estimation model of nitrogen content in apple leaves was established, and the optimal model of nitrogen content in apple leaves in spring was established. The optimal estimation model of nitrogen content in leaves in the spring tip stopping period was based on the random forest model of fractional differential order 2. The modeling accuracy determination coefficient R^2 reached 0.891, RMSE was 0.0841, and RPD was 2.1396. The determination coefficient R^2 of the fitting results of the verification set was 0.617, RMSE was 0.1251, and RPD was 1.7105. It provides a theoretical basis for further estimation of nitrogen content by leaf spectra and provides a reference for hyperspectral study of apple leaves. At the same time, it also provides theoretical basis and technical support for the application of apple leaf spectrum for

nutritional diagnosis, accurate fertilization and remote sensing inversion^{19,20}.

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