

Simulated Reflectance of Apple Trees in Canopy Level Based on the PROSAIL Model and HJ-1A-HSI Data

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Abstract

Using the PROSAIL radiation transfer model and HJ-1A-HSI data to simulate the canopy reflectivity of apple trees, this study lays the foundation for the inversion of canopy parameters. Taking Qixia City of Yantai City, Shandong Province as the research area, the apple tree was taken as the research object, and the hyperspectral reflectance, LAI and sample GPS of apple canopy were measured in the field. The parameters required for the PROSAIL model were obtained by experimental methods. The model simulates the reflectivity; the HSI image data is preprocessed, and the canopy reflectivity is extracted by GPS coordinates. The PROSAIL model and the HSI image simulated reflectance were fitted to the measured apple canopy reflectivity. The decisive factor (R^2) of the simulated reflectance and the measured reflectance of the PROSAIL model was 0.9944, and the relative error (RE%) was 0.1845. The HSI data simulated reflectance and measured reflectance. The coefficient of determination is 0.9714 and the relative error is 0.6202. Both have achieved good fitting effects and can be used for inversion studies of apple canopy parameters.

Key words: Apple Tree; PROSAIL Model; HJ-1A-HSI; Canopy Reflectivity

1 INTRODUCTION

The HJ-1A-HSI data is hyperspectral image data, the wavelength range is 450 nm~950 nm, and the number of bands is 115. Compared with other remote sensing data, the spectral resolution is greatly improved ^[1-2], the information is more Rich, widely used in atmospheric composition monitoring ^[3-4], water environment testing ^[5], landscape ecological research ^[6] and vegetation growth monitoring ^[7-8]. The PROSAIL Radiation Transfer Model is a physical model that converts reflectance from leaf scale to canopy scale and is widely used to estimate vegetation biochemical parameters ^[9-12]. This model greatly improves the feasibility and accuracy of spectral index quantitative inversion of vegetation parameters ^[13]. Domestic and foreign scholars have used the simulated spectral data of the two to conduct a lot of research on the inversion of vegetation parameters. He Li et al ^[14] comparatively analyzed GF-1, HJ-1, and Landsat-8 data to estimate the leaf area index of winter wheat. Chen Xueyang et al ^[15] used multispectral CCD data and hyperspectral data of environmental satellites to invert the wheat leaf area index. Yin Fang et al ^[16] used HSI data to establish three vegetation indices of RVI, NDVI and MSAVI and combined with ground data for modeling analysis. It was found that the correlation between the three vegetation indices and leaf area index was extremely significant. Qiu Sai ^[17] combined GLAS and HJ-1A-HSI hyperspectral imagery to estimate the area of forest aboveground biomass, and obtained good inversion accuracy. Li Shumin et al. ^[18] used MODIS and ASTER data with different spatial resolutions to invert the wheat leaf area index in a certain region based on the PROSAIL model. The results show that the physical model has higher inversion reality than the statistical model. Cheng Xiaojuan et al

^[19] used the PROSAIL model to simulate the canopy spectral data of winter wheat, and combined with the water spectral index to establish an estimation model of canopy vegetation moisture. The research has achieved good results. In this study, apple trees in Qixia City were used as research objects. The PROSAIL radiation transmission model and HJ-1 star HSI data were used to simulate the canopy reflectance of apple trees, in order to accurately invert the canopy parameters and estimate the apple yield. The foundation is convenient for guiding fruit production.

2 MATERIALS AND METHODS

2.1 Overview of the Study Area

Qixia City (120°33'—121°15' E, 37°05'—37°32' N) is located in the northeast of Shandong Province, in the hinterland of Jiaodong Peninsula, covering a total area of approximately 2017 square kilometers. The average elevation is 177.82 m. The annual average temperature in the region is 11.3 °C. The average ground temperature is 13.6 °C. The average annual sunshine hour is 2660 h. The average frost-free period is 207d. The annual average precipitation is 640mm-846mm. Qixia belongs to the warm temperate East Asian monsoon type semi-humid climate, which has the characteristics of rain and heat at the same time. The natural environmental conditions are especially suitable for apple growth.

In this study, the image range and quality status of the image are taken into consideration. In the street (town), the area where the image is not covered or with a large amount of cloud cover is removed. The final study area is shown in Figure 1, which shows the location of the sample points.

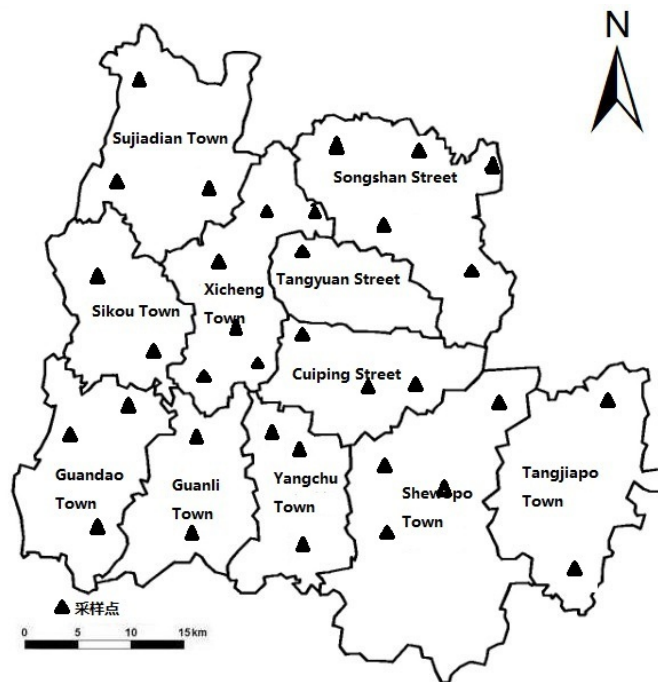


FIG. 1 ADMINISTRATIVE DIVISION AND SAMPLING POINT LAYOUT OF THE RESEARCH AREA

2.2 Sample Collection and Acquisition of Apple Canopy Spectral Data

The collection of experimental samples was carried out on September 21-22, 2015, when the autumn shoots of Qixia apple trees stopped. In the Qixia city, 34 orchards were randomly selected (as shown in Figure 1). A representative 100 m × 100 m square was selected as the sample area in each orchard, and the coordinates of the center point were measured by GPS. Randomly select three fruit trees in each plot that can represent the basic growth of the orchard. In the four directions of the east, west, south and north of the canopy, three layers of healthy, non-destructive, regular and similar leaves are collected. 12 pieces per tree, a total of 1224 leaves. Put them into the storage bags according to their respective sample areas. Put it in the safe with ice pack inside and bring it back to the lab as soon as possible.

The instrument for measuring the canopy spectral data of the near-surface is based on the American ASD Field Spec 4 portable ground spectrometer with an instrument band range of 350~2 500 nm. Among them, the sampling interval of 350~1 000 nm is 1.4 nm, the spectral resolution is 3 nm, the sampling interval of 1 001~2 500 nm is 2 nm, and the spectral resolution is 8 nm. Choose a sunny, cloudless day without a wind. The specific measurement time is 10:00-15:00. When measuring, first use the standard whiteboard to calibrate. The spectrometer is connected with 5 m fiber. The angle of view of the probe is 25 ° and the direction is vertical downward. Adjust the distance between the probe and the canopy at any time based on the size of the apple tree crown to ensure that the field of view covers the entire canopy. Ten spectra were measured for each canopy. The arithmetic mean of the three canopies within the sampling point is taken as the final sampled data for the sample. The value directly measured by the ground spectrum spectrometer is the DN value, which is converted into the spectral reflectance by ViewSpec software. Finally, a total of 2151 band data is output by resampling.

2.3 PROSAIL Model Parameter Acquisition

The PROSAIL model consists of a blade optical property model (PROSPECT) and a canopy radiation transport model (SAIL). The PROSPECT model was first proposed by Jacquemoud et al. ^[20]. The model consists of four parameters, namely the internal structural parameters of the leaves (N), the dry matter content of the leaves (C_m), the equivalent water thickness (C_w) of the leaves, and the chlorophyll of the leaves. Content (C_{ab}). The SAIL model is gradually derived from the Suit model by Verhoef ^[21] and is applicable to the radiation transfer model describing the dichroic reflectivity of the vegetation canopy. Using existing structural and environmental parameters, it is possible to simulate canopy reflectance at any solar height and direction of observation. The PROSAIL model used in this paper is coupled by the PROSPECT-5 blade optical model and the 4SAIL canopy radiation transmission model. The specific model is shown in Equation 1.

$$\rho = \text{PROSAIL}(N, C_{ab}, C_{ar}, C_w, C_m, ALA, LAI, hspot, \theta_s, \theta_o, \varphi_{so}, C_{brown}, P_{soil}) \quad (1)$$

In the formula, N is the leaf structure parameter, C_{ab} is the chlorophyll content, C_{ar} is the carotenoid content, C_w is the equivalent water thickness, C_m is the dry matter content, ALA is the average leaf dip angle, LAI is the leaf area index, and $hspot$ is the hot spot parameter. (The ratio of the average size of the blade to the height of the crown), θ_s is the solar zenith angle, θ_o is the observed zenith angle, φ_{so} is the solar azimuth, C_{brown} is the brown matter, and P_{soil} is the soil reflectivity.

The instrument used to measure LAI is the LAI-2200 canopy analyzer manufactured by LI-COR, USA. The sensor measures the transmitted light at five angles above and below the canopy, and uses the radiation transfer model to calculate the leaf area index of the vegetation canopy ^[22]. The equivalent water thickness, dry matter content, chlorophyll and carotenoid content were obtained by laboratory chemical methods, using ovens, balances, spectrophotometers and other instruments ^[23-24]. The solar zenith angle, the observed zenith angle and the solar azimuth are obtained directly from the image information.

2.4 HJ-1A-HSI Data Acquisition and Preprocessing

HJ-1A-HSI image data can be obtained directly from the "China Centre For Resources Satellite Data and Application" website. Due to the limitation of specific sampling time and the time, range and image quality of HSI data in the study area, this study used the HJ-1A satellite image taken from September 17, 2015 - "HJ1A-HSI-452-70 -A1-20150917-L20002627860".

The entire process of simulating reflectivity is processed by data reading, absolute radiance value conversion, vertical strip removal, atmospheric correction, and geometric precision correction ^[25-26]. Among them, the data reading uses the instrumental software ENVI_HJ1A1B_ToolsV3.3 which is specially used for data conversion of environmental satellite data. The absolute radiance value conversion is to divide the affected product by the expansion factor (100). The vertical strip removal adopts the global stripping method. The pixel is subjected to sub-band linearization correction by the difference between the column mean value of the pixel and its standard deviation and the band mean and its standard deviation. The image is rotated first and then the strip is

removed. Finally, the anti-rotation of the image. Atmospheric correction uses the fast line-of-sight atmospheric analysis of spectral hypercubes. According to the imaging time and geographical location, the atmospheric model of mid-latitude summer, the type of rural aerosol, the inversion of water vapor channel 820 nm, and the visibility of 40 km are selected. The main atmospheric effects: absorption of gases such as H₂O, O₃, O₂, CO₂, CH₄, N₂O, and scattering of atmospheric molecules and aerosols are considered. The geometrically corrected Alos image data is used as the reference image. According to the characteristics of HSI data, the Image to Image tool is used to complete the geometric fine correction with a correction accuracy of 0.4 pixels.

2.5 Canopy Reflectivity Simulation and Verification Method

The measured apple canopy reflectance data was resampled using the spectral response function of the HSI data. The re-sampled measured reflectance data is fitted to the image reflectance before and after pre-processing, respectively. The accuracy is evaluated by determining the coefficient (R^2) and the relative error (RE%). Among them, the larger the coefficient of determination, the smaller the relative error, the better the fitting effect of the simulated reflectance.

The accuracy evaluation of the simulated reflectance of the PROSAIL model was designed to verify the feasibility of the model for inverting apple canopy parameters. Input the known parameters into the model, constantly change the unknown parameter values and use the cost function to determine the optimal parameter values to obtain the PROSAIL simulated reflectivity. Take the 400~1 000 nm band range and fit the reflectivity of the measured canopy in the same band range. R^2 and RE% are also used to evaluate the accuracy.

The specific calculation methods of R^2 and RE% are shown in formulas (2) and (3), and the cost function formula is shown in formula (4).

$$RE\% = \frac{1}{n} \sum_{i=1}^n \frac{y_i - \hat{y}_i}{y_i} \times 100\% \quad (2)$$

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

Where y_i is the measured canopy reflectance value, $\hat{y}_i$ is the image canopy reflectance value or the model simulated reflectance, $\bar{y}$ is the average of the measured values, and n is the number of bands.

$$\text{Cost}(X) = \sum (R_{\text{mes}} - R(P, X))^2 \quad (4)$$

Where R_{mes} is the measured canopy reflectivity, R is the model simulated reflectivity, P is the known parameter of the model, and X is the unknown parameter of the model.

3 RESULTS AND ANALYSIS

3.1 Simulation of Apple Canopy Reflectivity Based On HJ-1A-HSI Data

After pre-processing, the image is cropped according to the boundary of the study area, and the background zero value is removed, as shown in Figure. 2. The sample reflectance is extracted from the image before and after preprocessing according to the GPS coordinate information. The measured apple canopy reflectance data was resampled using the spectral response function of the HSI data to obtain the same measured canopy data as the image band. The comparison between the measured canopy data, the image data before pre-processing and the pre-processed image data (simulated reflectance data) is shown in Figure 3. It can be clearly seen from the figure that the simulated spectral curve is closer to the true apple canopy spectral curve. The spectral reflectance values before pre-processed are higher than the measured values in almost the entire band. There is no correlation between the trends of the two reflection curves. The pre-processed spectral curve is basically consistent with the measured canopy spectral curve. The reflectance value between 1 and 78 bands (460.04 nm~706.54 nm) is slightly higher than the measured value. The reflectance values between the 79 and 115 bands (711.50 nm to 951.54 nm) are lower than the measured values.

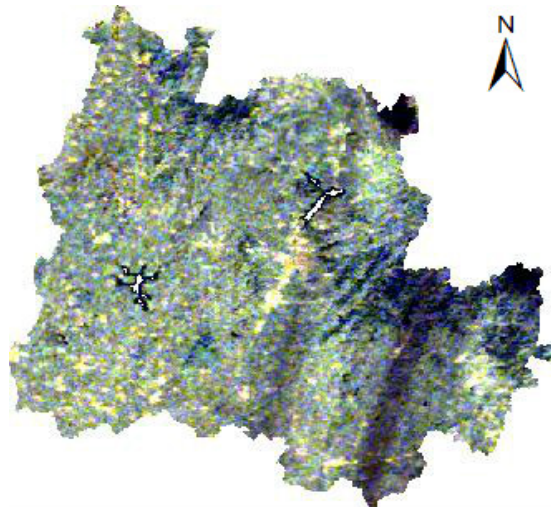


FIG. 2 THE HJ1A-HSI IMAGE CLIPPING RESULTS OF THE RESEARCH AREA

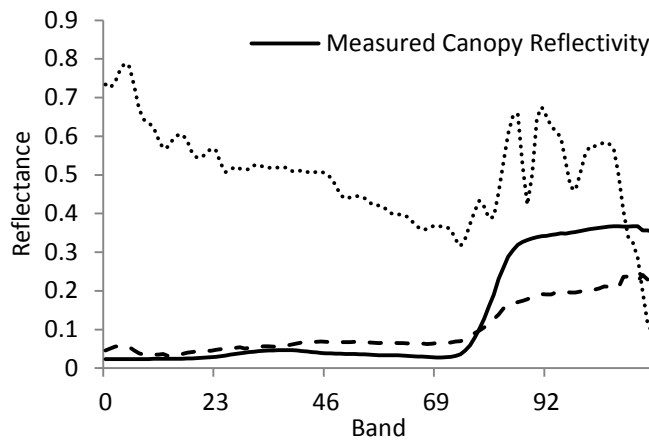


FIG. 3 COMPARISON OF IMAGE REFLECTANCE DATA BEFORE AND AFTER PRETREATMENT WITH MEASURED CANOPY DATA

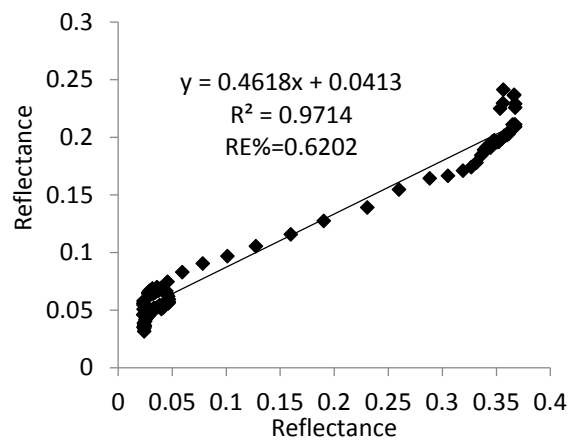


FIG. 4 COMPARISON BETWEEN MEASURED CANOPY REFLECTANCE AND CANOPY REFLECTANCE SIMULATED BY HSI IMAGE

The measured canopy reflectance data were fitted to the image reflectance data before and after the pretreatment. As shown in Figure 4, the coefficient of determination is 0.9714, and the relative error RE% is 0.6202. Through the preprocessing process of HJ-HSI data, the data quality of the image is greatly improved, and the consistency with the ground measured canopy data results is good, which is conducive to accurate inversion of canopy parameters.

3.2 Apple Canopy Reflectance Simulation Based on PROSAIL Radiation Transfer Model

The input values of the parameter leaf area index, chlorophyll content, carotenoid content, dry matter content, and equivalent water thickness were taken as the experimental average of 34 samples. The input values of the solar elevation angle, the observed zenith angle and the azimuth parameters are obtained directly from the HSI image data. Psoil, ALA, Cbrown, hspot, and other parameters are based on previous studies to take constants as model input values [20] [21]. The value of N is the value corresponding to the minimum cost function. The specific input values are shown in Table 1. The parameters are input into the model to obtain the apple canopy simulated reflectivity. In order to more intuitively represent the degree of fit between the simulated reflectance and the measured reflectance, and taking into account the reflectance range of the satellite image, only the reflectance data of 400 nm to 1 000 nm is used for fitting. It can be seen from Figure 5 that the PROSAIL model simulates a higher degree of overlap between the canopy reflectance and the measured apple canopy reflectance. The trend is basically the same, especially in the 700~800 nm band, the reflectivity is basically coincident.

TABLE 1 MODEL INPUT PARAMETER VALUES WHEN SIMULATING REFLECTIVITY

Input parameters	Parameter value	Input parameters	Parameter value
LAI	3	Psoil	0.1
Cab($\mu\text{g}/\text{cm}^2$)	82	ALA	45
Car ($\mu\text{g}/\text{cm}^2$)	2	hspot	0.2
Cm (g/cm^2)	0.0246	Cbrown/($\mu\text{g}/\text{cm}^2$)	15
Cw(cm)	0.0165	N	1.5
	46.839°		317.938°
	0°		

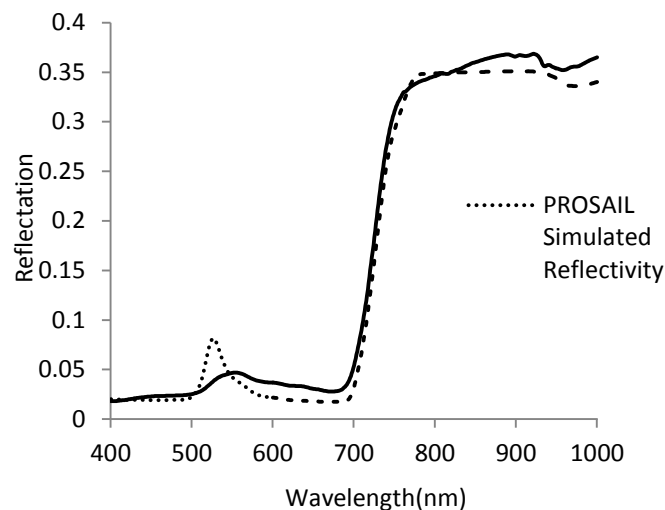


FIG. 5 COMPARISON BETWEEN MEASURED CANOPY REFLECTANCE AND CANOPY REFLECTANCE SIMULATED BY PROSAIL MODEL

The measured canopy reflectance data is fitted to the model simulated reflectance data, as shown in Figure 6. The determination coefficient R^2 is 0.9944 and the RE% is 0.1845. The fitting accuracy of the two is high, indicating that PROSAIL can be used for the inversion of apple canopy parameters.

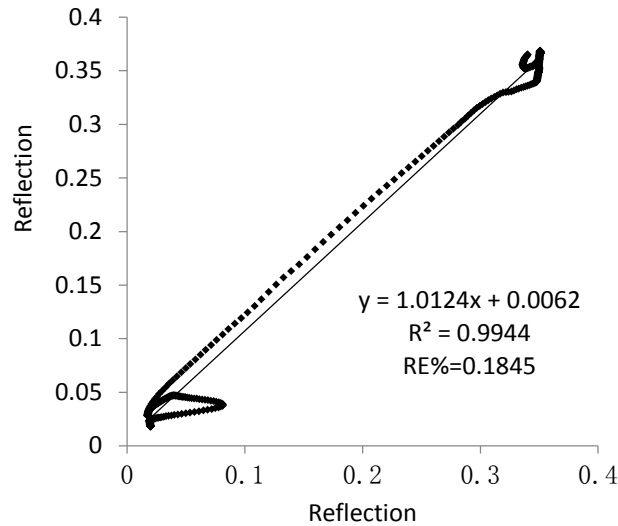


FIG. 6 CONTRAST BETWEEN PROSAIL MODEL SIMULATES CANOPY REFLECTANCE AND MEASURED CANOPY DATA

4 CONCLUSION

In this study, apple trees in Qixia City of Shandong Province were used as research objects. In the long-term autumn stage of apples, the simulated reflectance of apple canopy was studied by using HJ-1A-HSI data and PROSAIL radiation transfer model. Through the pretreatment of HSI data, the simulated reflectance of hyperspectral image is closer to the true vegetation reflectivity, and the results of fitting with the measured apple canopy reflectivity are in good agreement. The coefficient of determination R^2 is 0.9714 and the relative error RE% is 0.6202. The leaf area index, chlorophyll content, carotenoid content, dry matter content, equivalent water thickness and other parameters were obtained by experimental measurement methods. Combined with image data and previous studies, solar elevation angle, observation zenith angle and azimuth angle were obtained. The apple canopy reflectance simulated by PROSAIL model and N value is obtained by minimizing the cost function. The coefficient of determination of the measured reflectance and reflectance simulated by the PROSAIL model is 0.9944, and the relative error RE% is 0.1845. The simulated reflectivity of both has achieved a good fitting effect, which provides a basis for determining and adjusting the parameter setting of the PROSAIL model for inverting apple canopy parameters. It lays a foundation for large-area and high-efficiency non-destructive monitoring of vegetation canopy parameters and guiding fruit tree production by environmental satellite hyperspectral remote sensing technology.

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