Hyperspectral parameters and prediction model of soil moisture in apple orchards

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Abstract. In this study, the apple orchard of Shuangquan town in mountainous and hilly area of central Shandong Province was taken as the research area. The relationship between the ratio spectral index (RSI), difference spectral index (DI) and normalized difference spectral index (NDSI) and soil moisture content in the range of 400nm-2450nm was explored, and then a quantitative estimation model of soil moisture content was build. The results show that the correlation between soil moisture content and spectral reflectance can be improved by different spectral index calculation. The sensitive modeling areas determined by RSI, DI and NDSI are all near the third water absorption peak, among which RSI (R2304, R2081), RSI (R2306, R2080), RSI (R2306, R2081), RSI (R2307, R2079), RSI (R2307, R2080), RSI (R2307, R2081), RSI (R2308, R2080) and RSI (R2308, R2081) the PLSR regression equation constructed for independent variables has the best estimation effect, the largest determination coefficient ($R^2 = 0.7918$), and the smaller Root Mean Square Error (RMSE= 0.0054). The selection of full band spectral index can better extract effective information, and significantly improve the accuracy and adaptability of soil moisture spectral estimation model.

1. Introduction

Water is the material basis for the growth of fruit trees and the carrier for fruit trees to absorb nutrients. Soil moisture affects the yield of orchard and the quality of fruit. At present, China's orchards are changing from extensive management of flood irrigation to fine management of drip irrigation, infiltration irrigation and integration of water and fertilizer. How to quickly and real-time monitor soil moisture is one of the keys to guide apple production precision management. The traditional method of soil moisture measurement is not effective and can’t meet the requirements of modern orchard production. In recent years, hyperspectral remote sensing technology has been applied to the spectral estimation of soil water content because of its fast, non-destructive, zero pollution and large amount of information. However, most orchard sites are located in mountainous and hilly areas. Due to the influence of geography, climate, soil texture and other factors, the soil spectral signal is weak, and the traditional spectral estimation method can’t accurately estimate the soil moisture content. It is found that the use of spectral index can eliminate background noise and improve the accuracy of model prediction [1-2], so it is widely used in hyperspectral inversion of surface parameters. However, due to the limitation of technology, most of the researches at home and abroad focused on the calculation of spectral index of sensitive bands, and failed to fully tap the information hidden in soil spectrum [3-5].

In order to solve the difficulties in spectral estimation of orchard soil water content, the apple
orchard in Shuangquan town in mountainous and hilly area of central Shandong Province was selected as the research area. The relationship between soil water content and spectral reflectance was studied. Three different spectral indices in the range of 400-2400nm were analyzed band by band, and the spectral characteristic parameters of soil water were determined, and the quantitative estimation model of soil water content was established.

2. Materials and methods

2.1. Overview of the study area
The study area is located in Shuangquan town, Changqing District, Jinan City, Shandong Province. The town is located in the northwest foot of Mount Tai, which belongs to the hilly region of middle and low mountains. It belongs to warm temperate semi humid continental monsoon climate, and the precipitation is mainly concentrated in summer. The selected apple orchard covers an area of about 33hm², and the apple variety is Gala. The tree age is 5 years, and the soil type is brown soil.

2.2. Collection of soil sample data and acquisition of spectral data
The soil samples were collected on August 1, 2018. Based on the chessboard sampling method, 140 fruit trees were evenly selected in the apple orchard, and the sampling point was 30cm from the horizontal direction of the apple tree trunk. Undisturbed soil 0-10cm below the surface of soil was collected with ring knife(Φ=10cm, h=6.37cm). After sealing and numbering, put the ring knife in the plastic box and take it back to the laboratory for subsequent analysis.

ASD FieldSpec 3 spectrometer was used. The spectral reflectance of undisturbed soil was obtained in a dark room with artificially controlled illumination. Put the ring knife containing undisturbed soil on the black rubber with reflectance of approximately 0, the field of view angle of the probe is 25° and 15cm away from the soil sample, and the incident angle of the light source is 45°. In the process of measurement, the white board with reflectivity of 1 is used for correction in time [6].

2.3. Determination of soil moisture
The soil moisture content was determined by drying method. The soil moisture content was 100% × (fresh soil mass - dried soil mass) / dried soil mass. Table 1 shows the statistical characteristics of soil moisture in different sampling points.

| Sampling        | Sample size | Maximum(%) | Minimum(%) | Mean(%) | Standard deviation |
|-----------------|-------------|------------|------------|---------|--------------------|
| Modeling set    | 100         | 16.21      | 7.96       | 12.41   | 0.0191             |
| Verification set| 40          | 15.16      | 9.63       | 12.49   | 0.0014             |

2.4. Data processing
The measured spectral data were converted into spectral reflectance by ViewSpecPro, and the breakpoint was corrected. Then, SG smoothing is carried out in MATLAB, and the damaged bands of 350-399nm and 2401-2500nm with large spectral edge noise are deleted, and then the original spectral reflectance is output.

The ratio spectral index (RSI), difference spectral index (DI) and normalized spectral index (NDSI) are selected as the spectral indexes, the formula is:

\[ RSI(R_1, R_2) = \frac{R_1}{R_2} \]  
\[ DI(R_1, R_2) = R_1 - R_2 \]  
\[ NDSI(R_1, R_2) = \frac{(R_1 + R_2)}{(R_1 - R_2)} \]

R1 and R2 represent the spectral reflectance of any two bands in the sample spectrum[7].

With the help of matrix operation of MATLAB, the spectral index of sensitive band range and full band range are obtained respectively, and the correlation coefficient matrix with soil water content is obtained, which is displayed by contour map. The relationship between soil spectrum and soil water
content is analyzed, and the band combination of sensitive spectral index is determined.

2.5. Establishment and accuracy evaluation of soil moisture quantitative model
Partial least squares regression analysis (PLSR) was used for modeling. The random sampling method was used to divide the collected samples into modeling set and validation set, in which 100 samples in the modeling set were used to construct the quantitative estimation model of soil water content, and 40 samples in the validation set were used to test the accuracy and stability of the quantitative model.

Four parameters R2, RMSE, RMSEP and slope were selected to evaluate the stability and accuracy of the model. The measured values and estimated values of the verification set are visualized by origin2018.

3. Results and analysis

3.1. Spectral characteristics of apple orchard soil
As can be seen from the spectrum curve of apple orchard soil (figure 1), the spectrum curve characteristics of soil under different water content are roughly the same, the spectral reflectance of soil shows an overall downward trend with the increase of water content. The spectral reflectance of soil shows a monotonous increasing trend in the range of 400-1350nm, and two absorption peaks appear at 1410nm and 1920nm. The spectral reflectance is relatively stable in the range of 1450-1850nm. A third absorption peak appears at 2200nm.

Figure 1. Spectral reflectance curve of soil in sample area.

Figure 2. Correlation between soil spectral reflectance and soil moisture.

3.2. Screening of spectral parameters
According to the correlation coefficient between R and soil water content in figure 2, 8 sensitive bands (R1471, R1473, R1885, R1886, R2017, R2018, R2266, R2267) are determined at the peak of different bands. In MATLAB, the RSI, DI and NDSI of 8 sensitive bands and any two bands in the range of 400-2400nm are calculated respectively. Then the correlation between spectral index and soil water content was calculated, and the contour map was drawn. It can be seen from figure 3 that the absolute value of correlation coefficient between spectral index and soil water content calculated by sensitive band is not more than 0.8. The correlations between RSI(R2266, R2018), DI(R1886, R1885), NDSI(R2266, R2018) and soil water content were 0.78, 0.61 and 0.78, respectively. Compared with the correlation coefficient of the original spectral reflectance R, the correlation is not improved. Therefore, the commonly used spectral index calculation with a small number of sensitive bands as data sources can’t screen out the effective spectral information, and its practicability is not strong.
(RSI: Ratio spectral index; DI: Difference spectral index; NDSI: Normalized difference spectral index. The same below)

Figure 3. Matrix of correlation coefficient between soil spectral index and soil moisture content. Compared with the common methods, the correlation of spectral index calculation based on the full band range is significantly improved. The sensitive areas of soil water content modeling determined by the original spectral reflectance of soil under RSI, Di and NDSI spectral indexes are mainly concentrated near the third absorption band of soil water content. Based on the sensitive spectral areas, several groups of wavelength combinations with relatively large correlation coefficient under different spectral indexes are determined (Table 2). The optimal band combinations of the three kinds of indexes are RSI(R2306, R2080), DI(R2305, R2094), NDSI(R2069, R2307).

Table 2. Spectral parameter information

| Independent variable | RSI(x) | DI(x) | NDSI(x) | R | R |
|----------------------|--------|-------|---------|---|---|
| X1                   | (R2304, R2081) | 0.9121 | (R2304, R2093) | 0.9082 | (R2067, R2308) | 0.8998 |
| X2                   | (R2306, R2080) | 0.9147 | (R2304, R2094) | 0.9072 | (R2069, R2306) | 0.9001 |
| X3                   | (R2306, R2081) | 0.9127 | (R2305, R2092) | 0.9084 | (R2069, R2307) | 0.9024 |
| X4                   | (R2307, R2079) | 0.9140 | (R2305, R2093) | 0.9091 | (R2070, R2307) | 0.9015 |
| X5                   | (R2307, R2080) | 0.9131 | (R2305, R2094) | 0.9099 | (R2071, R2307) | 0.9021 |
| X6                   | (R2307, R2081) | 0.9128 | (R2305, R2095) | 0.9081 | (R2072, R2306) | 0.9017 |
| X7                   | (R2308, R2080) | 0.9129 | (R2306, R2093) | 0.9072 | (R2072, R2307) | 0.9016 |
| X8                   | (R2308, R2081) | 0.9124 | (R2306, R2095) | 0.9074 | (R2073, R2306) | 0.9005 |

3.3. Quantitative inversion of soil moisture in apple orchard

3.3.1. Construction of soil water content estimation model. Taking 8 sensitive bands (R1471, R1473, R1885, R1886, R2017, R2018, R2266, R2267) as independent variables, the estimation model is established based on
PLSR (Table 3). The coefficient of determination of the model is small ($R^2=0.6037$), and the root mean square error is 0.012, so the prediction result is poor.

Taking the sensitive RSI, DI and NDSI determined in Table 2 as independent variables, the soil water content estimation models were established based on PLSR method (Table 3). Comprehensive comparison showed that the coefficient of determination of partial least squares regression model based on RSI sensitive band combination was the largest ($R^2 = 0.82$), and RMSE was close to zero (RMSE = 0.0081), which could better estimate soil water content.

| Independent variable | Partial least squares regression equation | $R^2$ | RMSE   |
|----------------------|------------------------------------------|-------|--------|
| R(x1,…… ,x8)        | $y=-0.1927-0.0255x1-0.0402x2-0.1045x3-0.0708x4-0.1763x5-0.1640x6+0.0582x7+0.0339x8$ | 0.6037 | 0.012  |
| RSI(x1,…… ,x8)      | $y=-1.1216+0.6193x1+0.5136x2+0.2633x3-0.1538x4+0.0025x5+0.2095x6+0.0084x7+0.2140x8$ | 0.8193 | 0.0081 |
| DI(x1,…… ,x8)       | $y=0.1366+0.0114x1+0.2640x2+0.1384x3-0.4008x4+0.6437x5+1.0243x6+2.1979x7+2.7256x8$ | 0.7712 | 0.0091 |
| NDSI(x1,…… ,x8)     | $y=0.1609+0.00045x1+0.00034x2+0.00023x3-0.00006x4-0.000027x5-0.000013x7-1.4968x8$ | 0.6276 | 0.0116 |

3.3.2. Test of soil moisture estimation model in apple orchard. The validation set ($n=40$) was used to test the above model, and the 1:1 relationship between the measured value and the estimated value was made with origin2018 (figure 4).

![Figure 4. Measured and predicted values of soil water content](image)

The results show that the model based on RSI sensitive band combination has the best verification effect, the coefficient of determination ($R^2 = 0.7919$) is the largest, the root mean square error (RMSE = 0.0054) is close to zero, and the slope (slope = 0.8733) is close to 1. Which indicates that the prediction results of the model fit well with the measured values, and its performance is better than the estimation models under DI and NDSI. Therefore, the estimation model based on RSI sensitive band combination can realize the rapid and accurate estimation of soil moisture in apple orchard in the study area.

4. Conclusion
(1) The spectral index calculation based on the sensitive band can’t improve the correlation, and the sensitive modeling area of soil water content determined by the spectral index calculation based on the whole band (RSI, Di, NDSI) is located near the third absorption band of soil water.

(2) The model based on spectral index can significantly improve the estimation accuracy of soil moisture in apple orchard. The model with sensitive RSI as independent variable has the largest coefficient of determination ($R^2 = 0.7918$) and smaller root mean square error (RMSE = 0.0054). The predicted value of the model is in good agreement with the measured value, which can be effectively applied to the real-time estimation of soil moisture in apple orchard monitor.

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