

Eliminating the interference of soil moisture and particle size on predicting soil total nitrogen content using a NIRS-based portable detector



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ABSTRACT

Applying near infrared reflectance spectroscopy (NIRS) on farmlands can effectively estimate the total nitrogen (TN) content of soil online. We developed a NIRS-based portable detector of soil TN content that measures spectral data at 940, 1050, 1100, 1200, 1300, 1450, and 1550 nm. The soil spectral data are sensitive to external environmental conditions, particularly soil moisture content and particle size. The interference of these factors on predicting soil TN content must be eliminated when using the portable detector. First, soil samples were collected from a farm in Beijing, China, and scanned using the detector to obtain their absorbance data under varying soil moisture and particle size. Second, absorbance correction method and mixed calibration set method were proposed to correct the original spectral data and to eliminate the interference of soil moisture and particle size, respectively. The absorbance of the soil sample at 1450 nm exhibited a high correlation with soil moisture content. Thus, a moisture absorbance correction method (PMAI) was proposed to normalize the original spectral data into the standard spectral data and consequently eliminate the interference of soil moisture. A NIRS-based mixed calibration set based on the additivity of NIR spectra was produced with varying particle sizes, separated from the original soil samples, to eliminate the interference of soil particle size on the measurements of the portable soil TN detector. An estimation model of soil TN content was established based on the corrected absorbance data at six wavelengths (940, 1050, 1100, 1200, 1300, and 1550 nm) using an algorithm of the back propagation neural network. The correlation coefficient of calibration, correlation coefficient of validation, root mean square error of calibration, root mean square error of prediction, and residual prediction deviation were used to evaluate the model. Compared with the model used the original spectral data, the accuracy and stability of the new model were significantly improved. These methods could efficiently eliminate the interference of soil moisture and particle size on predicting soil TN content.

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1. Introduction

Near infrared reflectance spectroscopy (NIRS) technology can effectively analyze the physical and chemical properties of compounds such as H, O, C, and N. NIRS can successfully analyze soil parameters and food properties (Ben-Dor and Banin, 1995; Bogrekci and Lee, 2005a; Viscarra Rossel et al., 2006; Gomez et al., 2008; Reeves and Smith, 2009; Pan et al., 2009; Reeves, 2010; Yu, 2011; Wang et al., 2013). Soil spectral features in the near infrared wavebands are highly correlated to the vibration modes of functional groups (i.e., the chemical bond of H and C, N, and O) (Li et al., 2006). The total nitrogen (TN) content in the soil

is a macro-element that plays an important role in soil nutrition (Sinfield et al., 2010). Estimating soil TN content has been greatly progressing in the past decades based on NIRS (Reeves et al., 2001; He et al., 2007; Zheng et al., 2008; Gao and Lu, 2011). However, several problems must be solved first. Soil NIR reflectance is sensitive to external environmental conditions such as soil particle size and moisture content (Bowers, 1965; Mouazen et al., 2005, 2006; Zheng, 2007; Kuang and Mouazen, 2011; Yang et al., 2012). Many scholars have discussed and analyzed the effects of soil particle size and moisture content on forecasting soil parameters (Bogrekci and Lee, 2005b, 2006; Bao et al., 2007; Barthes et al., 2008; Brichlemeyer and Brown, 2010; James and Reeves, 2010; Minasny et al., 2011). Several studies have also proposed methods for eliminating these interferences. Bogrekci and Lee (2005b, 2006) researched the effects of soil particle size and moisture content on

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predicting the availability of phosphorus in the soil using a spectrometer. Consequently, several forecasting models of phosphorus with different soil particle sizes were established based on multiple linear regression (MLR) and partial least squares regression (PLSR). Both correlation coefficients of calibration and validation exceeded 0.90. Minasny et al. (2011) used the external parameters orthogonalization (EPO) method to eliminate the interference of soil moisture content on predicting soil organic matter (OM) and discussed the optimal parameters of the EPO method and PLSR factors. James et al. (2010) established the models of soil OM and pH with PLSR, which showed that the effect of soil moisture content on predicting soil OM was more serious than that of pH value. Barthes et al. (2008) observed that the models of soil OM, soil TN, and soil organic carbon with particle sizes of less than 2 mm were better than those of other particle sizes.

Although the estimation models of several soil parameters have made great progress, the combination effects of soil particle size and moisture content on predicting soil TN has rarely been explored. Thus, a combined algorithm must be generated to eliminate the estimation error caused by soil particle size and moisture content. Eliminating the effect of soil moisture content and particle size on estimating soil TN content will be easy once data on soil moisture content and soil particle are obtained. However, obtaining these data using the in-site portable soil TN detector is difficult. This paper aims to use the developed portable soil TN detector to analyze the effects of soil particle size and moisture content on predicting soil TN and propose corresponding algorithms to eliminate these two external factors and achieve highly accurate estimations of soil TN in situ measurement.

2. Materials and methods

2.1. Portable soil TN detector

A portable soil TN detector was developed based on NIRS (An et al., 2014). The detector used a LED lamp house as its light source and consisted of an optical unit and a control unit. Fig. 1 shows the overall structure of the soil TN detector, while Fig. 2 shows its optical fiber structure. Fig. 3 shows the soil TN detector prototype. The optical unit included seven near-infrared LEDs (Iwasaki Co., Ltd, Sapporo, Japan) in separate housings, a shared LED drive circuit, a shared incidence and reflectance Y-type optical fiber (Beijing Glass Research Institute, Beijing, China), a probe, and an InGaAs photoelectric sensor (Titan Electro-Optics Co., Ltd, Beijing, China). We manufactured and assembled the LED drive circuit and probe. The control unit included an amplifier circuit with two operational

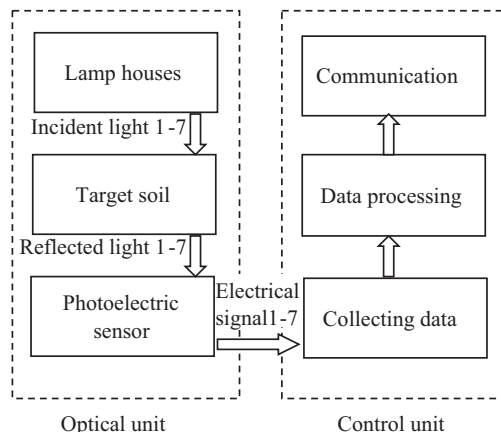


Fig. 1. Overall structure of the portable soil TN detector.

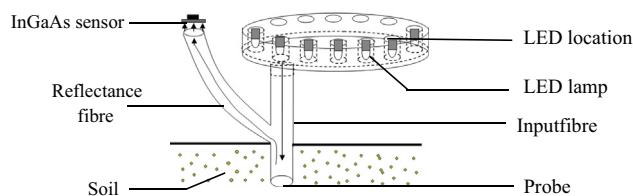


Fig. 2. Optical fiber structure of the portable soil TN detector.

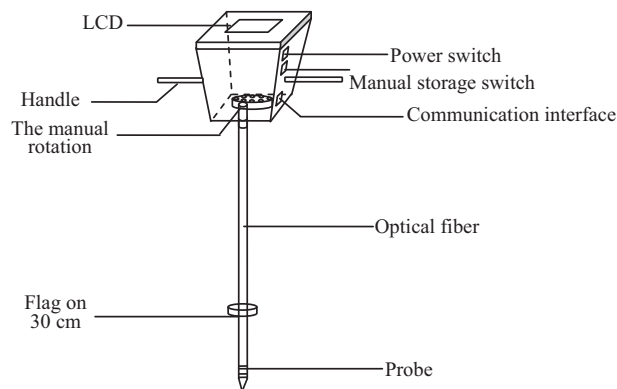


Fig. 3. Prototype of the portable soil TN detector.

amplifiers, CA3140 and LM358 (Intersil Corporation, Palm Bay, USA), an R-C filter circuit, an analog-to-digital converter (A/D) circuit with an IC chip MAX187 (Maxim Integrated, San Jose, USA), an LCD display with IC chip LCM128645zk (Beijing Qingyun Hi-tech Development Co., Ltd, Beijing, China), and a CH376 type of U-disk storage component (Nanjing QinHeng Electronics Co. Ltd, Nanjing, China).

Seven LEDs with different wavelengths were selected as our sensitive wavebands. Zheng (2007), Zheng et al. (2008, 2009, 2010), and An et al. (2011) employed several algorithms to estimate soil TN based on NIR spectral reflectance measured by a MATRIX-I Fourier transform near-infrared spectrophotometer (Bruker Optical Company, Germany). These algorithms included MLR, back propagation neural network (BP-NN), wavelet analysis, and support vector machine (SVM). Zheng and An et al. compared the results of these algorithms and suggested that the BP-NN model was best suited to estimate the soil TN content, and the recommended sensitive wavelengths were 1550, 1450, 1300, 1200, 1100, 1050, and 940 nm. The calibration R^2 was 0.85 and the validation R^2 was 0.77, which were highly precise for real-time estimation of soil TN.

The detector was pushed 300 mm into the target soil. The LEDs were rotated manually to align with the Y-type optical fiber. The optical signal at each wavelength was then transferred from the LED to the surface of the target soil. The reflected light was acquired from the soil surface and transferred to the photoelectric sensor, which converted the optical signal to an electrical signal. Subsequently, the electrical signal was digitized and the absorbance at each wavelength was calculated. All seven absorbance data were used as input for the estimation model of soil TN content. Finally, the calculated soil TN content was displayed on the LCD and simultaneously stored in the U-disk.

The absorbance was selected as the spectral parameter. A standard whiteboard made of polytetrafluoroethylene (Anhui Institute of Optics and Fine Mechanics, Hefei, China) was used to obtain the absorbance of the soil samples. First, the soil TN detector probe was placed on the standard whiteboard and the output voltage V_i of the instrument was measured. The probe was then pushed into

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