Catena 165 (2018) 106–114

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Photography measured-value magnification improves local correlation maximization-complementary superiority method of hyperspectral analysis of soil total nitrogen

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ARTICLE INFO

Keywords:
reflectance spectra
photography measured-value magnification
local correlation maximization-complementary superiority
soil total nitrogen

ABSTRACT

Accurate remote retrieval of soil total nitrogen (TN) content is a challenging task due to many factors including soil color. The objective of this study was to investigate whether the photography measured-value magnification (PMM) method improves estimation accuracy by reducing the influence of soil color, when combined with the local correlation maximization-complementary superiority (LCMCS) method. Soil samples were collected from three areas of subsided land in Renqiu, Changzhou, and Fengfeng District, all located in Hebei Province, China. Soil spectral reflectance was measured using an ASD FieldSpec 3 spectrometer in a laboratory environment and the TN content was determined by the Kjeldahl method. After PMM analysis, the LCMCS method was used to build models for TN estimation. The results indicate that the LCMCS model of the PMM group produced lower prediction errors (Coefficient of determination [R^2] = 0.893, root mean square error of validation [RMSEV] = 0.090, mean relative error of validation [MREV] = 5.721%) when compared with the local correlation maximization-partial least squares regression (LCM-PLSR) model of the PMM group and the models of the conventional group. Overall, the PMM method combined with LCMCS has great potential to improve the estimation accuracy of TN content and enriches the choice of observation method.

1. Introduction

Soil total nitrogen (TN) describes a major component of soil, and is an indicator of soil fertility. Analysis of TN content based on traditional chemical testing methods are relatively laborious, time consuming, and expensive (Hou et al., 2012; Zhou et al., 2016). The development of real-time dynamic methods for measurement of TN content are therefore required. In recent years, hyperspectral remote sensing monitoring of TN has attracted increasing attention and has recently resulted in a large number of research outputs (Gmur et al., 2012; Anne et al., 2014; Kim et al., 2014; Lin et al., 2014; Sun et al., 2014; Gomez et al., 2015; Babaeian et al., 2015). However, the accuracy of TN estimates needs further improvement.

Models for measurement of TN using hyperspectral data benefit from interactions within TN and soil reflectance in the visible/near-infrared region. However, the soil texture, clay mineralogy, soil organic matter (SOM), soil color also have a considerable effect on the soil spectrum, making it harder to extract the relationship between TN and spectral information. Therefore, several attempts have been made to seek statistical methods for TN assessment. With the advantage of processing huge data matrices, partial least squares regression (PLSR) has been successfully applied to hyperspectral data for predicting TN content (Thomas and Haaland, 1990; Vohland et al., 2016). For example, Chang et al. (2005) applied the PLSR method for the rapid quantification of several soil properties including TN. Udelhoven et al. (2003), Vagen et al. (2006) and Shi et al. (2013) all used the PLSR method to predict TN content with laboratory visible/near-infrared reflectance (Vis/NIR) data for soil samples, and the R^2 of three experiments reached separately 0.62, 0.93, 0.76. In general, previous studies have confirmed that the PLSR method is one of the most efficient methods used in developing reliable TN estimation models. In recent years, a new TN estimation method based on the local correlation maximization (LCM) de-noising method, PLSR and adaptive neuro-fuzzy inference systems (ANFIS) has been presented, which is known as local correlation maximization-complementary superiority (LCMCS) (Lin et al., 2015). The LCMCS approach solved the difficult issue of how to reduce noise while retaining the details in hyperspectral data and, while maintaining the advantages of PLSR and ANFIS, has produced ideal results.

Although there have been major research achievements in

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https://doi.org/10.1016/j.catena.2018.01.028
Received 7 May 2017; Received in revised form 21 January 2018; Accepted 25 January 2018

predicting TN using hyperspectral remote sensing technology, the estimation accuracy is still affected by many factors, including soil color (Leone and Escadafal, 2001; Rossel et al., 2009; Ustin et al., 2009). Munsell Soil Color Charts are the most commonly tools to determine soil color. For example, based on the soil color determined by Munsell Soil Color Chart, Dematte et al. (2011) used the stepwise multiple linear regression method to predict soil organic matter, and results were obtained for Ultisols and Oxisols (both having an R^2 of 0.73). Moritsuka et al. (2014) obtained soil color values through a soil color reader (SPAD-503; in the Munsell color system) and used correlation analysis to estimate the TN content. Researchers also used the RGB schemes to determine soil color, Doi and Ranamukhaarachchi (2007) quickly obtained soil color values using the photographic technique and then developed ideal TN estimation models. However, little research into combining rapid color-acquiring technology with hyperspectral remote sensing technology has been conducted to date.

The research objectives of this study were as follows: (i) to propose an effective method to quickly analyze the soil color values and reduce the influence of soil color; and (ii) to determine whether this method improves estimation accuracy when combined with the LCMCS method. To achieve these goals, the photography measured-value magnification (PMM) method was proposed, and TN estimation models were established based on the PMM and LCMCS method. The performance of the TN model built by PMM and LCMCS was then compared and evaluated using the LCM-PLSR model of the PMM group and three further models (the conventional group).

2. Materials and methods

2.1. Sample preparation

Topsoils (0–30 cm) were randomly sampled from three subsided lands (red regions in Fig. 1) of Renqiu (Fig. 1a; 38°42′N, 116°7′E), Changzhou (Fig. 1b; 38°42′N, 116°7′E), and Fengfeng District (Fig. 1c; 36°20′N, 114°14′E), all located in Hebei Province, China (Lin et al., 2015). The aim of sampling topsoil only was to obtain a dataset with variability in soil type and TN concentration, and the samples cover different landuse types, including grassland, cropland, forest and waste land. In these three regions, subsidence had been resulted from the overexploitation of oil, groundwater and coal, respectively. And the status of surface subsidence were all obtained by Interferometric synthetic aperture radar (InSAR) technique, which can be found in Lin et al. (2015). The soil types were defined based on Chinese Soil Taxonomy System, which was developed by Institute of Soil Science, Chinese Academy of Sciences (http://www.issas.ac.cn/ztwz/200910/t20091015_2551708.html). Dominant soils in the subsided lands of Changzhou City and Renqiu City are all semi-hydromorphic soil, and in Fengfeng District is Semi-Luvisols. A total of 372 samples (122 from Renqiu, 125 from Changzhou and 125 from Fengfeng) were used in this study. All soil samples were air-dried and sieved using a 2-mm sieve, and these samples were then put into Ziploc plastic bags and then stored. Kjeldahl method and Dumas combustion method are two of the most commonly used methods for determining the TN content (Kjeldahl, 1883; Horita, 2006). The Kjeldahl method has disadvantages in safety and cost, but always has higher precision than the combustion method (Marco et al., 2002). In this study, TN content of each soil sample was determined by the Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China (Measured by Kjeldahl method).

2.2. Measurement and data processing

Spectral data of each soil sample was measured by an ASD FieldSpec®3 spectrometer (Analytical Spectral Devices, Boulder, USA). The spectral range of the spectrometer covers 350–2500 nm, with a spectral resolution of 3 nm at 700 nm, and 10 nm at 1400 nm and 2100 nm. The sampling range in the 350–1000 nm is 1.4 nm and 2 nm in the 1000–2500 nm range. Each sample was placed into a transparent plastic container with a diameter × height of 10 × 2 cm, and illuminated with a halogen lamp of 50 W (~3200 K color temperature). Ten readings were obtained through the soil surface with a constant angle (approximately 30°) at a distance of 30 cm from the light source. Reflectance was calibrated against a white Spectralon® panel with 100% reflectance, and each average of ten consecutive readings was treated as the original spectra of the corresponding soil sample. The entire process was operated in a dark room.

2.3. Retrieval model

In this study, 200 samples (72 from Renqiu, 65 from Changzhou and 63 from Fengfeng) were used to build estimation models, and 172 samples (53 from Renqiu, 60 from Changzhou and 59 from Fengfeng) were used in verification. Standard derivative analysis is always employed to reduce low-frequency noise from spectral data, therefore, the first derivative differential (FDR) transformed by original spectral reflectance (REF) was used in modeling. Lin et al. (2015) indicated that the TN estimation models established by LCM-PLSR and LCMCS methods produced better results than that of PLSR. Thus, in addition to the PLSR method, the LCM-PLSR and LCMCS were used to retrieve the TN contents. Most importantly, to quickly analyze the soil color values and reduce the influence of soil color, PMM method was proposed and applied in building the TN models. After PMM analysis, the LCMCS method was used to retrieve the TN contents. To determine whether

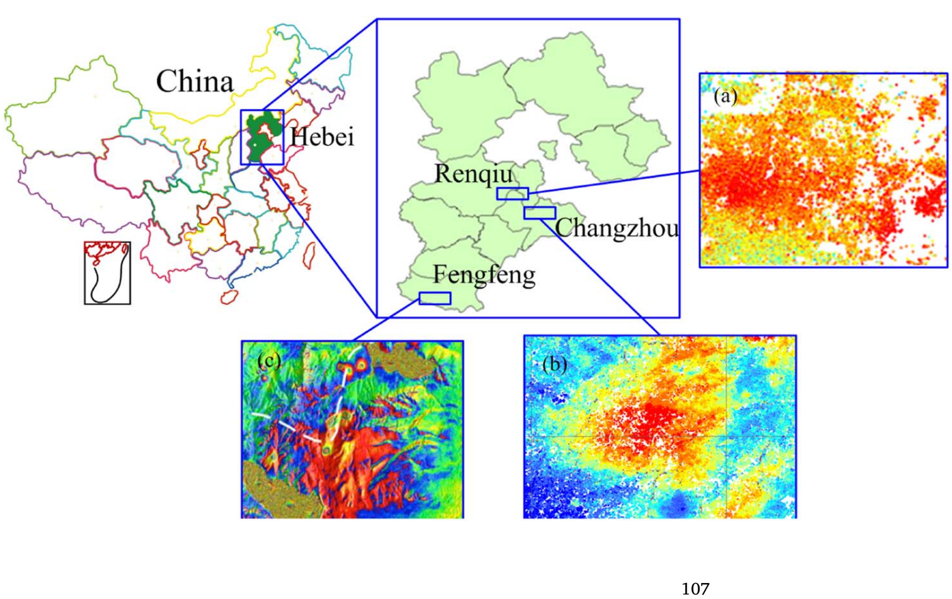

Fig. 1. Soil sampling locations in subsided land (red regions) of Renqiu (a), Changzhou (b), and Fengfeng (c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)