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Estimation of Organic Matter Content in Coastal Soil Using Reflectance Spectroscopy

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ABSTRACT

Rapid determination of soil organic matter (SOM) using regression models based on soil reflectance spectral data serves an important function in precision agriculture. "Deviation of arch" (DOA)-based regression and partial least squares regression (PLSR) are two modeling approaches to predict SOM. However, few studies have explored the accuracy of the DOA-based regression and PLSR models. Therefore, the DOA-based regression and PLSR were applied to the visible near-infrared (VNIR) spectra to estimate SOM content in the case of various dataset divisions. A two-fold cross-validation scheme was adopted and repeated 10 000 times for rigorous evaluation of the DOA-based models in comparison with the widely used PLSR model. Soil samples were collected for SOM analysis in the coastal area of northern Jiangsu Province, China. The results indicated that both modelling methods provided reasonable estimation of SOM, with PLSR outperforming DOA-based regression in general. However, the performance of PLSR for the validation dataset decreased more noticeably. Among the four DOA-based regression models, a linear model provided the best estimation of SOM and a cutoff of SOM content (19.76 g kg^{-1}), and the performance for calibration and validation datasets was consistent. As the SOM content exceeded 19.76 g kg^{-1}, SOM became more effective in masking the spectral features of other soil properties to a certain extent. This work confirmed that reflectance spectroscopy combined with PLSR could serve as a non-destructive and cost-efficient way for rapid determination of SOM when hyperspectral data were available. The DOA-based model, which requires only 3 bands in the visible spectra, also provided SOM estimation with acceptable accuracy.

Key Words: deviation of arch, multiple regression, partial least squares regression, reflectance spectra, soil organic matter

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INTRODUCTION

Soil organic matter (SOM) is an important indicator of soil fertility, and it can affect other physical and chemical properties of soil. Conventional SOM analyses relying solely on the ground samples, however, are slow, destructive and spatially limited. Consequently, they often fail to meet the requirements for modern precision agriculture or regional soil survey. On the other hand, reflectance spectroscopy has been actively explored as a way to estimate SOM due to its rapidity, convenience and capability of estimating multiple components simultaneously (Ben-Dor, 2002; Nanni and Demattê, 2006). Thus, reflectance spectroscopy is now regarded as a promising alternative to the conventional methods for soil studies (Shi *et al.*, 2006; Ben-Dor *et al.*, 2008).

Many researchers have investigated various approaches to estimate SOM using reflectance spectroscopy, either using numerous (hundreds of) narrow visible near-infrared (VNIR) bands collected by the hyperspectral sensors or using a selection of VNIR bands that changes sensitively to the variations in SOM. In the former category, the partial least squares regression (PLSR) method was widely used in recent years to calibrate various VNIR spectral models to SOM (Mouazen *et al.*, 2010; Stevens *et al.*, 2010; Shen *et al.*, 2013; St. Luce *et al.*, 2014; Shi *et al.*, 2014; Conforti *et al.*, 2015). This modeling approach, integrating principal component analysis and multiple linear regression analysis, simplifies data structure and constructs predictive models (Xu, 2005). The PLSR, taking SOM into account, compresses the information of soil reflectance spectra, which effectively improves the result. However, it is difficult to specify the corresponding bands that are sensitive to SOM.

On the other hand, multiple regression analysis has been used as a popular modeling approach in early stu-

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dies to predict SOM using a small number of VNIR bands (Krishnan *et al.*, 1980; Dalal and Henry, 1986; Liu *et al.*, 2007). The multiple regression method is relatively simple and easy to derive, and it is essential to select the spectral bands mostly affected by SOM when using hyperspectral reflectance datasets collected for systematically varying SOM contents. Sha *et al.* (2003) and Viscarra Rossel *et al.* (2006) compared the absorption bands of SOM and found that the reflectance in the range of 500–800 nm was significantly affected by SOM. Brown *et al.* (2006) suggested that the strongest absorption by SOM occurred at 600 nm. Soils with a high SOM content tend to have a concave spectral reflectance curve between 500 and 1 300 nm, whereas soils with a low SOM content tend to have a convex spectral reflectance curve (Huete and Escadafal, 1991; Conforti *et al.*, 2013).

The "deviation of arch" (DOA) of the spectra at 600 nm is a parameter characterizing the concavity and convexity of spectral reflectance curves in the range of 550–650 nm. This parameter objectively reflects the difference between the yellow and red bands of soil spectra without being influenced by salt content in the soil (Xu and Dai, 1980), and consequently, it can be used effectively to estimate SOM. However, DOA-based regression models have not been widely used in later research due in part to the other hyperspectral reflectance models (*i.e.*, PLSR) outperforming them. Nonetheless, utility of the methods that require a smaller number of multispectral bands, such as DOA-based regression, is still important considering a large number of multispectral airborne and space-borne sensors with relatively long historical records.

The aim of this work was to apply the DOA-based regression and PLSR to the VNIR spectra to estimate SOM content in soil of coastal areas and compare the performance of the two methods. In order to achieve high statistical power, the reflectance measurements of the coastal soil samples were resampled to subsamples for two-fold cross-validation using a bootstrapping (Efron and Tibshirani, 1993).

MATERIALS AND METHODS

Site, sampling and chemical analysis

The study area is located in the coastal areas of Dongtai City, northern Jiangsu Province, China (32°35′–32°57′ N and 120°07′–120°53′ E, Fig. 1). This region has a mean annual precipitation and temperature of 1 042.3 mm and 14.6 °C, respectively. Divided by the Fan Gong Dike, the soil in the western region was derived from lacustrine sediments, whereas the soil in the eastern region from coastal sediments.

Seventeen soil profiles were logged and eight topsoil (0–5 cm) samples were collected in the eastern region of the Fan Gong Dike (Fig. 1). The sampling depth intervals in each profile were 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 60–80 and 80–100 cm. Two samples of profile were missing. A total of 142 soil samples were obtained. The samples were ground in the laboratory after air-drying. The SOM content was determined using the potassium dichromate method, which varied

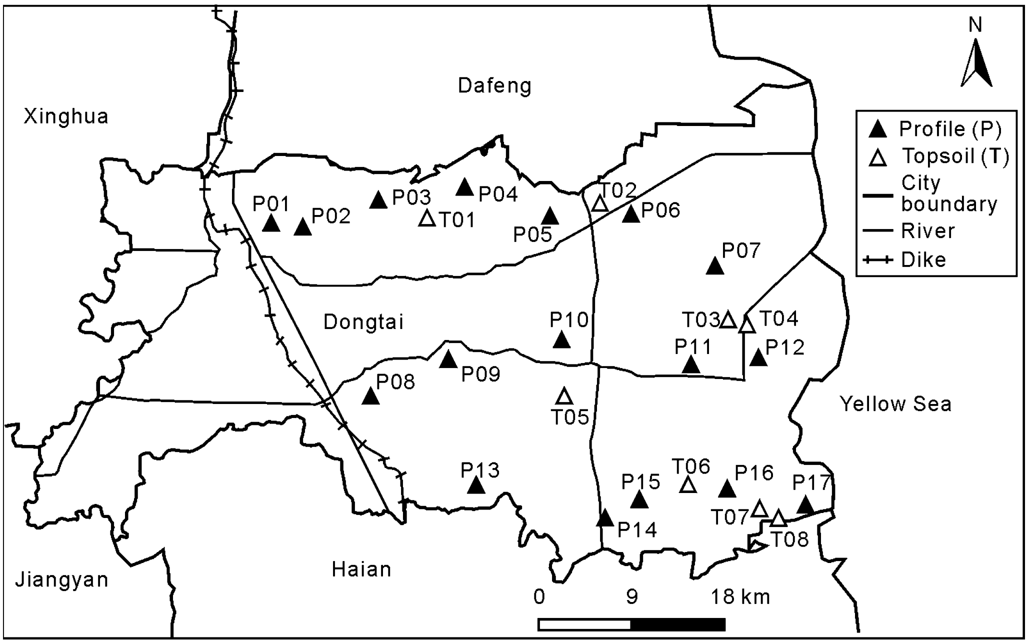

Fig. 1 Distribution of the soil sampling sites (profiles and topsoils) in Dongtai City, northern Jiangsu Province, China.