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Assessing soil organic matter of reclaimed soil from a large surface coal mine using a field spectroradiometer in laboratory

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ABSTRACT

Soil organic matter (SOM) for topsoil is one of most important indicators to support the success of mine ecological reclamation. SOM varies along the artificial mine landscape characterized by different bench-slopes of dump. Reflectance using field spectroscopy can provide useful information on the assessment of punctual soil variation, and has the advantages of speed and efficiency. The aims of this study were to 1) explore the characteristic spectrum of reclaimed soil of different landforms, 2) develop a key spectral-ratio index for evaluating SOM content, and 3) establish a SOM prediction model using the Partial Least Square Regression-Support Vector Machine (PLS-SVM) method. Based on comprehensive analysis of the relationship between SOM content and corresponding spectral reflectance in soils from different landforms, the results showed a new derived spectral index would be useful for estimating SOM. The ratio spectral index ($R_{2294\ nm}$ / $R_{2286\ nm}$), calculated using available wavebands in the 350–2500 nm region, was proposed for use in the reliable estimation of SOM from downslope and midslope. The PLS-SVM calibration model for the raw spectrum, showed a high predictive accuracy for estimating the SOM content, with cross-validated R^2 of 0.95, and RMSE of 0.12. These outcomes provide a theoretical basis and technical support for estimations of SOM content using visible/near-infrared spectra in reclamation areas. It is proposed that the spectral difference index and model undergo further testing and optimization prior to wider application for observation of mine-reclamation ecosystems.

1. Introduction

The mining and processing of mineral resources, particularly those extracted by surface mining, which require the complete removal of vegetation, surface soil and bedrock, and the mixtures of removed soil and rock are commonly stored in large stockpiles or dumps. The reclamation of the topsoil covering the waste rock dump or tailing dump is a primary strategy used to restore vegetation and for landform stability. Monitoring the progressive changes in the soil conditions during reclamation until the soil properties can support self-sustaining plant growth is critical for successful reclamation programmes. The processes of soil formation over landscapes, along with reclamation-induced soil changes, have created soil variation and areas of varying reclamation age within different bench-slopes of a dump. Multiple, interactive soil properties influence the suitability of soil for reclamation. These are complex and vary spatially and temporally within the field of activity (Barnes et al., 2003). The traditional methods for the chemical analysis of soil properties are relatively complex, time consuming, and expensive. Reflectance can provide useful information for the assessment of punctual soil variation (Demattê and da Silva Terra, 2014) and has the advantages of speed and efficiency. Soil organic matter (SOM) is one of the main driving forces behind soil property prediction using soil spectroscopy (Vašát et al., 2014). The organic matter present in soils has distinct spectral features in the NIR region because of the relatively strong absorption overtones and combination modes of several functional groups [for example: aliphatic C—H, —COOH (carboxyl), —OH (hydroxyl), and N—H (in amines and amides)] present in organic compounds (Ben-Dor et al., 1997).

Many multivariate techniques have been used to build prediction models to extract quantitative information from spectral features. Partial Least Squares regression (PLS) yields the overall best results and is the most robust with respect to predicting the soil properties of soil types (Ge et al., 2014; Nocita et al., 2011; Viscarra Rossel et al., 2006). A Support Vector Machine (SVM) employs a set of linear equations,

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rather than quadratic programming problems, to obtain support vectors and has attracted attention and gained extensive application in spectral analysis. The integration of PLS-SVM results in better prediction accuracy than using only one model because PLS can remove unreliable information associated with the samples (Chauchard et al., 2004). The prediction accuracy of PLS-SVM models relies on a wide range of spectral bandwidths (Xuemei and Jianshe, 2013). Apart from multivariate techniques, spectral indices, which are calculated based on the sensitive wavebands related to the biophysical attributes, can be used to predict different soil properties. This approach has the advantage of applicability to various spectroradiometer sensors with different wavelength position, bandwidth or number of bands, and it is less complicated to apply in soil evaluation than multivariate techniques (Bartholomeus et al., 2008). Moreover, spectral indices might be applied to remote-sensing sensors to assess the land-surface parameters in arid areas on a landscape or regional scale.

It is difficult to use a general model to estimate the SOM content at the scale of local mining because the national soil VIS-NIR library outperforms local-scale models (Gogé et al., 2014). The local calibration of soil spectroscopic models of field sampling sets may be more accurate than national calibration (Wetterlind and Stenberg, 2010). Currently, traditional field sampling and extraction and digestion laboratory methods are the primary techniques used to assess soil properties during mine reclamation. The mining process, particularly for large surface mines, takes a few decades, and is followed by the mine reclamation project. Soil properties are important indicators for assessing reclamation and require long-term, effective, rapid monitoring techniques (Banning et al., 2008). There is strong potential for NIR spectroscopy to be used in the assessment of mine soil quality (Pietrzykowski and Chodak, 2014). Few studies exist on the quantitative estimation of the SOM content in the reclaimed mine soil of the Loess Plain region of China, which is covered with large mining areas. The main aims of this study include: 1) to explore the characteristic spectrum of reclaimed soil of different landforms, 2) to develop a key spectral-ratio index for evaluating SOM content, and 3) to establish a SOM prediction model using the PLS-SVM method.

2. Materials and methods

2.1. Description of mine reclamation

The Pingshuo Surface Coal Mine (PSCM) is located on the Loss Plateau in Central China. As one of the largest coal mines, PSCM has been active since 1987; however, the surface coalmine has been used for > 100 years. Given the environmental rules and regulations affecting mining, a reclamation project was undertaken in addition to the mining exploration. The study area is the west dump, which covers approximately 0.4 km^2 and is one of the reclaimed dumps of the PSCM (Fig. 1). The first reclamation project to create conditions for the substantial use of a dump was conducted at the west dump in 1993.

Soil substrates on the reclaimed dump consist of rock and coal gangue material from the waste rock dump. This substrate has poor structure, high stone content, and low content of organic matter, nitrogen, phosphorus, and other nutrients. Therefore, over 30 cm of topsoil (natural Loess) is used as a growth medium, to cover the dump and to support revegetation. Artificial revegetation is used to accelerate the revegetation process. The west dump vegetation is dominated by perennial grasses (*Medicago sativa* L.) on the dump slope and other species (*Hippophae rhamnoides* L., *Robinia pseudoacacia* L., *Populus simonii Carr*) on the dump flat.

2.2. Sampling design and analyses

Terrain factors play a role in the selection of an appropriate sample plan. Pennock (2003) developed landform segmentation procedures, including flat, upslope, mid-slope, and downslope categories, to analyse the topography-soil redistribution relationship. This landform segmentation

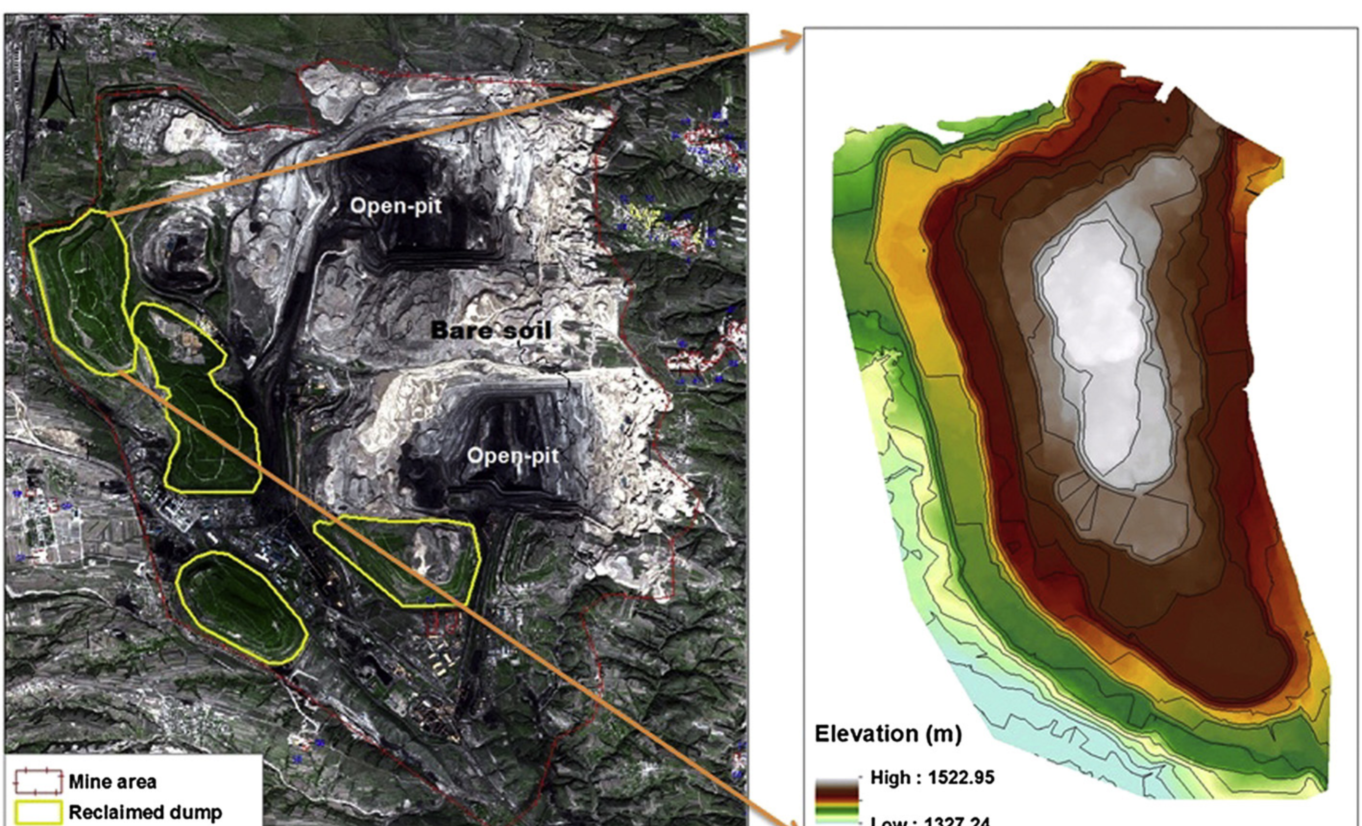

Fig. 1. Photograph of the mine area showing the open pits, bare soil and reclaimed dumps (left) and digital elevation model (DEM) of the studied dump (right).