Ecological Engineering 100 (2017) 237–245

Contents lists available at ScienceDirect

Ecological Engineering

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

# The development of topsoil properties under different reclaimed land uses in the Pingshuo opencast coalmine of Loess Plateau of China

Wei Zhou[a,b,*], Ke Yang[a,c,d], Zhongke Bai[a,b], Hangxin Cheng[c,d], Fei Liu[c,d]

[a] School of Land Science and Technology, China University of Geosciences, Beijing 100083, China
[b] Key Laboratory of Land Consolidation and Rehabilitation, The Ministry of Land and Resources, Beijing 100083, China
[c] Key Laboratory of Geochemical Cycling of Carbon and Mercury in the Earth's Critical Zone, Institute of Geophysical & Geochemical Exploration, Chinese Academy of Geological Sciences, Langfang 065000, China
[d] Institute of Geophysical & Geochemical Exploration, Chinese Academy of Geoscience, Langfang 065000, China

ARTICLE INFO

*Article history:*
Received 17 May 2016
Received in revised form
13 December 2016
Accepted 16 December 2016
Available online 31 December 2016

*Keywords:*
Soil properties
Land use
Loess Plateau
Pingshuo opencast coalmine
Geostatistical analysis

ABSTRACT

A better knowledge on soil development under different land use/cover is critical for restoring eco-environmental integrity in degraded mining areas. This study aims at evaluating the impacts of different reclaimed land uses on topsoil properties over time in an opencast coalmine located at Pingshuo, Shanxi province, China. Over two hundred soil samples at the depth of 0–30 cm were collected and analyzed by using descriptive statistic, spatial statistic, and geostatistical method. The results showed that significant differences existed in soil particle distribution, organic carbon (OC), total nitrogen (N), available potassium (AK), and cation exchangeable capacity (CEC) between reclaimed and unmined lands. However, pH, N, total phosphorus (P), available phosphorus (AP) and AK significantly differentiated from each other under different reclaimed land uses, while OC and N were the highest in cultivated soil, followed by forest, grass and barren soils. In addition, the results showed a strong global autocorrelation for pH, OC, N, P, AP and AK. Moreover, the changes of OC and N exhibited U-shape trajectory under forest and grass land, indicating that approximate 20 years were required for reclaimed forest and grass land to restore OC and N comparable to unmined land.



## 1. Introduction

Surface coal mining activities may lead to the destruction of ecological environment of coalmine areas by removing vegetation, altering soil physical and structural properties, changing topography, and disrupting surface and subsurface hydrologic regimes (Shrestha and Lal, 2010; Zhao et al., 2013; Adeli et al., 2013). Natural reestablishment of ecosystem in disturbed mining land is usually challenging owing to its compacted structure, disordered stratigraphic sequence, complicated surface material, and degraded soil properties (Cao et al., 2015; Zhang et al., 2015). To this end, artificial reclamation is required to improve soil quality and biomass productivity for the areas after coal mining, especially in the Loess Plateau of China with fragile ecosystem (Zhao et al., 2013; Kumar et al., 2015). A better knowledge on the interaction between vegetation rehabilitation and soil development is thus of particular significance to evaluate reclamation techniques, understand the ecological succession of revegetation, and guide future ecological restoration in the disturbed land (Kumar et al., 2015; Wang et al., 2016).

Considerable researches have been conducted on soil properties under a variety of land uses, such as agricultural lands (Wu et al., 2009; Cai et al., 2015), forest areas (Morisada et al., 2004; Chaturvedi et al., 2011) and urban regions (Pouyat et al., 2007; Horváth et al., 2015). However, relatively few attempts have been made in reclaimed coalmine areas where ecosystem recovery is severely constrained by soil quality degradation (Kumar et al., 2015; Wang et al., 2015a; Shrestha and Lal, 2010). For example, the destruction of soil physical properties and the depletion of soil nutrients severely constrain vegetation restoration in coalmine land, especially in the Loess Plateau region of China (Zhao et al., 2013; Wang et al., 2015a; Jiao et al., 2011).

As a typical arid and semi-arid region with fragile ecosystem, the Loess Plateau has long been targeted for soil studies within

* Corresponding author at: School of Land Science and Technology, China University of Geosciences, No. 29 Xueyuan Road, Haidian District, Beijing, 100083, PR China.
*E-mail address:* zhouw@cugb.edu.cn (W. Zhou).

http://dx.doi.org/10.1016/j.ecoleng.2016.12.028
0925-8574/

the context of ecological sustainability and climate change (Wang et al., 2010; Xin et al., 2015). Nevertheless, the changes of soil properties in reclaimed coalmine soil in the Loess Plateau are poorly understood, although a few age chronosequence studies have been reported on reclaimed mine soil properties in other regions, such as Lusatia district of Germany (Gast et al., 2001; Rumpel et al., 1999), Virginia and Ohio states of U.S.A. (Shrestha and Lal, 2010; Akala and Lal, 2000; Li and Daniels, 1994), and Raniganj Coalfield of India (Kumar et al., 2015). For the limited studies on mine soil properties in the Loess Plateau, they either addressed the spatial variability of soil properties or studied the influences of mining activities on soil properties (Wang et al., 2015a,b; Zhen et al., 2015). One exception is the exploration of the impacts of different plant species and time duration on reclaimed soil properties in a coalmine area in the northwestern Loess Plateau (Zhao et al., 2013). However, the research only exploited soil samples from the reclaimed forest land, lacking the comprehensive analysis of the influences of different reclaimed land uses on soil properties over time. Moreover, the sampling number of the majority of the studies conducted in the mined areas of Loess Plateau was limited and the analysis method was simple, without using the popular spatial and geostatistical methods.

Therefore, the objectives of current research were to (i) analyze the differences of soil physiochemical properties between reclaimed and unmined land, to (ii) assess the variations in soil properties under different reclaimed land uses using spatial and geostatistical methods, and to (iii) study succession law of soil properties over reclamation time in Pingshuo opencast mining area of the Loess Plateau.

## 2. Materials and methods

### 2.1. Study area

The study was carried out in a coalmine area located at Pingshuo of Northern Shanxi province, China (112°10′–112°30′E, 39°26′–39°36′N), as shown in Fig. 1. The study area belongs to the Loess Plateau region of China, where two-thirds of China's coal resource exists. As the largest opencast coalmine area in China, the Pingshuo opencast coalmine is suited along the border of Shanxi province, Shaanxi province and Inner Mongolia, covering the Antaibao, Anjialing, and Eastern opencast mines. This is an ecologically fragile area with typical arid and semi-arid continental monsoon climate. The mean annual rainfall is approximate 450 mm (with the minimum and maximum of 196 and 757 mm, respectively), 65% of which falls from June to September. However, the average annual evaporation of this region is about 2160 mm, which is more than 4.6 times of the rainfall. The altitude of the study area ranges from 1200 to 1600 m. The study area is dominated by chestnut soil, which is characterized by low levels of organic matter and poor structure.

The specific study area covered the dumps of Antaibao and Anjialing opencast mines and their surrounding unmined areas. The dumps of Antaibao opencast mine covered the Southern (Southern A), Western (Western A), Expanded Western (Expanded A) and Inner dumps (Inner A-1 and Inner A-2), and Anjialing opencast mine included the Western (Western B), Eastern (Eastern B), Inner (Inner A-2) and Nanshigou dumps (Nanshigou) (Fig. 1).

The major reclaimed forest vegetation species were *Hippophae rhamnoides, Robinia pseudoacacia, Ulmus pumila, Ailanthus altissima*, and pine (Table 1), and the reclaimed cultivated land was used for greenhouse vegetation plantation such as tomato and cucumber. Locust and pine were the main vegetation types in unmined forest land, and maize was the major vegetation grew in unmined agricultural land. Southern A, Western A, Inner A-1, Western B, Expanded A, Eastern B and Inner A-2 were reclaimed in 1992, 1994–1997, 1997, 2000, 2001–2003, 2005, and 2010–2013, respectively (Table 1). Thus, the reclamation age of different dumps ranges from 0 to 21 years.

### 2.2. Soil sample collection and analysis

In August and September 2013, a total of 203 sampling plots covering the study area were selected for the purpose of analyzing the impacts of different reclaimed land uses and age chronosequence on soil properties in Pingshuo opencast coalmine area (Fig. 1). A regular sampling grids with a distance of 500 m were initially designed using Geographical Information System (GIS) technique with the assistance of remotely sensed images. Each plot was then determined within the distance of 0–150 m to the candidate sites based on its representativeness and topographical conditions. For each sampling plot, five soil samples at the depth of 0–30 cm were collected using an auger and mixed to form a pooled sample of about 1 kg. Soil samples were then air-dried in the lab and passed through a 2-mm sieve for laboratory analysis.

Soil texture was measured using a laser particle-size analyzer-Longbench Mastersizer2000 (Malvern Instruments, Malvern, England). Soil particle size was categorized into three groups: <0.002, 0.002–0.02 and 0.02–2 mm based on the ISSS soil texture classification system, representing clay, silt, and sand, respectively (ISSS, 1929). Soil chemical properties were determined as follows: organic carbon (OC) and total nitrogen (N) were determined by the Walkley-Black and Kjeldahl methods (Nelson and Sommers, 1982; Rowland and Grimshaw, 1985), respectively; total phosphorus (P) and available phosphorus (AP) were extracted by using perchloric acid and sulfuric acid and sodium bicarbonate (Rowland and Grimshaw, 1985), respectively; available potassium (AK) was extracted with ammonium acetate (Helmke et al., 1996); soil pH was determined by using a glass electrode pH meter (Peech, 1965); cation exchange capacity (CEC) was established by using the compulsive exchange method (Rhoades et al., 1996; Sumner et al., 1996).

### 2.3. Statistical analysis methods

#### 2.3.1. Descriptive analysis

The descriptive analysis (i.e., mean, median, standard deviation, skewness, Kurtosis, Kolmogorov-Smirnov test) was firstly conducted to provide the basic descriptions of soil properties across different land uses. In addition, analysis of variance (ANVOA) was performed to explore the soil property differences between reclaimed and unmined soils. The significance of difference was assessed by using Tukey's post-hoc test. The descriptive analysis was performed in the SPSS 18.0 for Windows (SPSS Inc., Chicago, USA).

#### 2.3.2. Spatial analysis

The global and local Moran's $I$ were employed to characterize the spatial pattern of soil properties. The global Moran's $I$ shows the global spatial autocorrelation of a soil property (Anselin, 1995; Guo et al., 2013). The formula of the global Moran's $I$ is:

$$I = \frac{N\sum_i \sum_j w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{(\sum_i \sum_j w_{ij})\sum_i (x_i - \bar{x})^2}, \quad (1)$$

where $N$ is the sampling number, $w_{ij}$ is the matrix of spatial weight, $x_i$ and $x_j$ are the value of a soil property for $i$th and $j$th sample, and $\bar{x}$ refers to the average value of $x$. The value of global Moran's $I$ ranges from −1 to 1. The positive value indicates that similar values of a soil property cluster together; while it is opposite for the negative global Moran's $I$.