Geoderma 158 (2010) 352–358

Contents lists available at ScienceDirect

Geoderma

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

Ordination as a tool to characterize soil particle size distribution, applied to an elevation gradient at the north slope of the Middle Kunlun Mountains

Dongwei Gui [a,b,c], Jiaqiang Lei [a,c,*], Fanjiang Zeng [a,c], Michael Runge [d], Guijin Mu [a,c], Faxiang Yang [a,c], Juntao Zhu [a,b,c]

[a] Xinjiang Institute of Ecology and Geography ,CAS ,Urumqi, 830011, China
[b] Graduate School of the CAS, Beijing, 10039, China
[c] Cele National Station of Observation & Research for Desert-Grassland Ecosystem in Xinjiang, Cele, Xinjiang, 848300, China
[d] Department of Plant Ecology, Albrecht von Haller Institute of Plant Sciences, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany

ARTICLE INFO

Article history:
Received 1 July 2009
Received in revised form 26 May 2010
Accepted 3 June 2010
Available online 6 July 2010

Keywords:
Particle-size distributions (PSDs)
Ordination
CCA
Fractal dimension
Arid soils

ABSTRACT

Soil particle-size distribution (PSD) is one of the most fundamental physical attributes of soil due to its strong influence on other soil properties related to water movement, productivity, and soil erosion. Characterizing variation of PSD in soils is an important issue in environmental research. Using ordination methods to characterize particle size distributions (PSDs) on a small-scale is very limited. In this paper, we selected the Cele River Basin on the north slope of the Middle Kunlun Mountains as a study area and investigated vegetation and soil conditions from 1960 to 4070 m a.s.l. Soil particle-size distributions obtained by laser diffractometry were used as a source data matrix. The Canonical Correspondence Analysis (CCA) ordination was applied to analyse the variation characteristics of PSDs and the relationships between PSDs and environmental factors. Moreover, single fractal dimensions were calculated to support the interpretation of the ordination results. Our results indicate that a differentiation of 16 particle fractions can sufficiently characterize the PSDs in CCA biplots. Elevation has the greatest effect on PSDs: the soil fine fractions increase gradually with increasing elevation. In addition, soil pH, water and total salt content are significantly correlated with PSDs. CCA ordination biplots show that soil and vegetation patterns correspond with one another, indicating a tight link between soil PSDs and plant communities on a small scale in arid regions. The results of fractal dimensions analysis were rather similar to CCA ordination results, but they yielded less detailed information about PSDs. Our study shows that ordination methods can be beneficially used in research into PSDs and, combined with fractal measures, can provide comprehensive information about PSDs.

1. Introduction

Soil particle-size distribution (PSD) is one of the most fundamental physical attributes of soil due to its strong influence on other soil properties related to water movement, productivity, and soil erosion (Perrier et al., 1999; Bird et al., 2000; Huang and Zhang, 2005; Montero, 2005; Fooladmand and Sepaskhah, 2006). In a conventional particle-size analysis the mass fractions of clay, silt, and sand are differentiated. However, the size definitions of these main particle fractions are rather arbitrary, and this rough differentiation provides incomplete information (Bittelli et al., 1999) and is unsuitable to establish small-scale differences in soil PSDs (Wang et al., 2008).

Characterizing variation of PSDs in soils is an important issue in environmental research. The latest developments in the study of PSDs have focused on the use of fractal geometry (Turcotte, 1986; Tyler and Wheatcraft, 1992; Wu et al., 1993; Bittelli et al., 1999; Millan et al., 2003; Filgueira et al., 2006). Many single fractal and multifractal measures have been used to characterize the PSDs based on the need to obtain more data regarding particle fractions (Grout et al., 1998; Posadas et al., 2001; Montero and Martín, 2003; Montero, 2005). Most fractal measures attempt to characterize PSDs with parameters (i.e. fractal dimensions, D) that retain the most information. These parameters are then used to compare differences in the PSDs of soil samples. However, little attention has been paid to comparisons of changes in fraction content between soil samples and to quantitatively analyze the relationship between PSDs and environmental factors.

Quantitative methods have been used increasingly in ecological investigations since the 1950s (Zhang et al., 2008). Ordination and classification, which are effective multivariate techniques, have been

* Corresponding author. Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, 818 Beijing South Road, Urumqi, 830011, China. Tel.: +86 991 7885443; fax: +86 991 7885503.
E-mail address: desert@ms.xjb.ac.cn (J. Lei).

0016-7061/$ – see front matter. Crown Copyright © 2010 Published by Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2010.06.002

Table 1
Community characteristics along the altitude gradient on the north slope of the Middle Kunlun Mountains.

	Dominant species	Distribution range	Vegetation coverage	Vegetation type
Community I	*Calligonum roborovskii* + *Reaumuria soongonica* + *Sympegma regelii* + *Halogeton glomeratus*	1960–2800 m	Lower than 5%	Mountain desert
Community II	*Seriphidium rhodanthum* + *Stipa roborowskyi* + *Allium przewalskianum*	2900–3400 m	11–39%	Mountain desert grassland
Community III	*Poa* spp. + *Stipa purpurea*	3500–3600 m	35–73%	Mountain grassland
Community IV	*Kobresia humilis* + *Polygonum viviparum* + *Festuca rubra* + *Trisetum spicatum*	3700–4070 m	20–60%	Alpine steppe

widely used for analyses of community structure in vegetation ecology (ter Braak and Prentice, 1988; Mucina and Maarel, 1989; Mucina, 1997; Leps and Šmilauer, 2003; Zhang et al., 2008) and for research in other disciplines (Furse et al., 1984; Rubio and Escudero, 2000; Kent, 2006; Liu et al., 2007; Claassens et al., 2008). Ordination is useful in order to display the rows and columns of a two-way contingency table as points in a low-dimensional space, such that the positions of the row and column points are consistent with their attributes in the table (Greenacre, 1993; Giraudel and Lek, 2001). Normally, the objective of ordination is to generate hypotheses about the relationships between the composition of objects (e.g. vegetation) and the environmental or other factors which determine it (Greig-Smith, 1983). Various ordination methods are available, some of which have been widely used, e.g. Principal Components Analysis (PCA), Correspondence Analysis (CA), Canonical Correspondence Analysis (CCA) and Detrended Correspondence Analysis (DCA) (ter Braak and Prentice, 1988; Leps and Šmilauer, 2003). However, these methods have been mainly used in vegetation ecology and the application of ordination methods in studies of soil PSDs should be further discussed.

Because studies of small scale soil patterning in arid regions are rare (Rubio and Escudero, 2000), a typical arid mountain region, the north slope of the Middle Kunlun Mountains, Xinjiang, China, was selected as the research area for this study. CCA ordination was primarily employed to analyze the variations in the characteristics of PSDs and the relationships between the PSDs and environmental factors. Thus, the objectives of this study were to discuss the application of the ordination method to soil PSDs while analyzing the small scale soil patterning in a typical arid mountain region based on the results of the ordination. In addition, fractal dimensions (single dimension), which have been shown to be effective parameters in previous studies of PSDs, were used to support the interpretation of the ordination results.

2. Materials and methods

2.1. Site description

The Kunlun Mountains are located at the northern fringe of the Qinghai–Tibetan Plateau. The northern slope of the mountains is positioned above the Tarim Basin, constituting the natural boundary between the two physiogeographic regions (Guo et al., 1997). The Middle Kunlun Mountains are positioned between 77°24′ and 84° E and are extremely arid. Forests are scarce and the number of plant species is low (Cui et al., 1988). In this region, we selected the Cele River Basin (35°17′–37°07′N, 80°03′–81°07″E) as the main study area because of its relatively high plant species richness and its broad distribution of alpine meadows (Cui et al., 1988).

In the Cele River Basin, the elevation varies between 1300 and 5500 m a.s.l. Oases are mainly distributed between 1300 and 1900 m a.s.l. with a typical arid continental climate—an average annual temperature of 11.9 °C and annual precipitation of less than 35 mm. The elevation range between 2000 m and 3600 m has an alpine climate with an average annual temperature of 3.6 °C. Above 3600 m in elevation the temperature decreases gradually with increasing altitude and the precipitation increases, reaching 350 mm at an altitude of 4000 m (Gui et al., 2009).

2.2. Sampling and treatment

Sampling along the Cele River Basin was carried out from July to September 2008. Along the elevation gradient of 1960–4070 m, the main range of the natural vegetation, a sequence of 21 sample plots were established, most joined plots were separated by about 100 m in altitude, with the longest altitude separation of joined plots being 247 m and the shortest being 49 m based on changes in vegetation. Three squares were established randomly in each plot. The square size was 10 × 10 m for shrubs, which occur mainly in the range from 1960 to 2800 m a.s.l., and 1 × 1 m for herbs (2900 to 4070 m). The cover, height, and individual number of shrubs, and the cover and height of herbs were measured in each square. Altogether, 67 plant species were recorded in 63 squares. Soil samples (0–20 cm) were collected in the center of each square. A small amount of soil was sealed hermetically in an aluminum box to determine soil water content. Soil material was also placed in zip-lock bags for the measurement of soil PSDs, pH value, organic matter, and total salt content. All measurements were done in a laboratory.

Soil water content (SW) was calculated after drying the soil samples at a temperature of 105 °C until the weight did not change. The other samples were air-dried and hand-sieved through a 2-mm sieve to remove roots, stones and debris, and then analysed by standard soil testing procedures (Editorial Committee, 1996) to measure soil organic matter (SOM), pH value, and total salt (TA).

The particle size distributions of the <2 mm particle fractions was determined using the laser detection technique on a Malvern Mastersizer 2000 (Tate et al., 2007). Soil samples were pretreated by destroying organic matter using H_2O_2 (30%, w/w) at 72 °C. The aggregates were then dispersed using sodium hexametaphosphate (NaHMP) and ultrasonics lasting for 30 s. In all soil samples, the soil

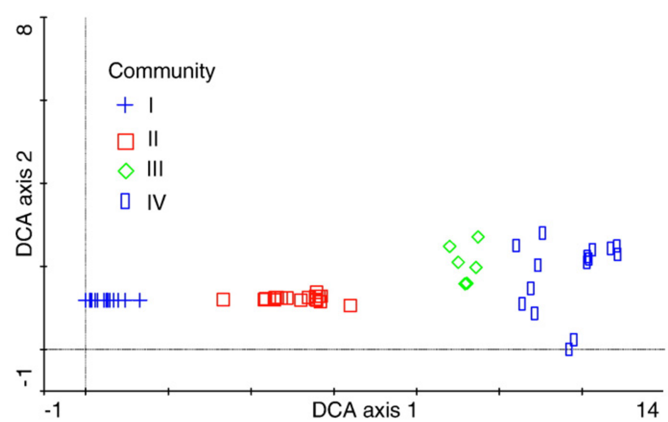

Fig. 1. Two-dimensional DCA ordination diagram of vegetation types (63 squares) along an altitudinal gradient on the north slope of the Middle Kunlun Mountains.