Structural Indicator Response of Soil Quality to Forestry Cultivation on the Loess Plateau of China

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Abstract: Soil quality is defined as "The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain biological productivity, maintain environmental quality, and promote plant and animal health". It is increasingly proposed as an integrative indicator of environmental quality, food security and economic viability. Soil structure is a base for its ecological function and sensitive to environmental disturbance, especially in the areas where soil material is chemically homogeneous. The present paper introduces a downscale method to evaluate soil structural quality of loess soil. Depth of topsoil, aggregate stability, organic matter, micromorphological characteristics and porosity, were investigated in loess soil in forestland and cultivated land, and statistically quantified by computer software. After 10 years cultivation, the 60cm-depth of topsoil had been completely depleted; soil porosity indicator had decreased by 69% and macro-pore space, by 26%. All the soil structural indicators imply the soil quality has greatly declined because the vegetation destroyed and the land cultivated. Soil erosion rate in the 10 year cultivated land was a thousand times of that in the forestland. It implies that soil structural indicators were a sensitive proxy indicator for soil quality in that region.
Keywords: micromorphology, structural indicator, soil quality, the loess plateau

1 Introduction

The soil, together with water and air, constitutes the most important natural resource. It is essential to wisely use this resource for sustainable development and feeding the growing world population (Arshad and Martin, 2002). In the past decades, a significant decline in soil quality has occurred worldwide through adverse side-effects of different human activities and contamination of inorganic and organic chemicals. On the other hand, the need for greater as well as more reliable agricultural yield is a continuing and ever-increasing global challenge. Thus, protecting soil resource and maintaining soil quality becomes a key international goal for sustainable use of soil.

There is a large body of literature linking soil quality indexing, assessment and modeling (e.g. Doran, 1994; Liebig and Doran, 1998; Jennifer *et al*., 2000). Many measuring system for assessing appropriate indicators have been suggested at different time scales for specific soils in various landscapes or agro-ecosystems with socio-economic concerns (e.g. Warkentin, 1995; Werner, 1999) Comparing those indicators with desired values (critical limits or threshold levels), soil specialists could give recommendations of land sustainable management to the farmers, managers and policy-makers. The present paper presents the response of structural indicator of loess soil to forestland cultivation with the concern of soil erosion.

2 Study area

The study area, Ziwuling forest region, is located in the middle of the Loess Plateau of China, a loess hilly-gully region with altitude of 920m—1,625m. It is at the northern boundary of a forest zone. It is affected by the prevailing northern monsoon in winter and southern monsoon in the summer. The annual precipitation ranges from 550 mm to 650 mm, and annual temperature ranges from 7℃ to 9℃. The soil is a typical loess which accumulated 100,000 years ago. It is a kind of loam soil with no significant change of soil texture or chemistry along the profile (Zhu, 1989; He, 1997), and is highly susceptible to erosion (Tang *et al*., 1991). The main vegetation species are *Q. liaotungensis, P. tabulaeformis Carr., P. davidiana, B. platyphyllum, S. viciifolia, O. davidiana, Z. guguba, A. gmelinii,* and *P. betulaefolia Bge* (He and Tang, 1999).

3 Material and methods

Two runoff natural plots were neighboringly setup on the ridge slope of forestland at Ziwuling of the Loess Plateau in 1989. One of them was cleaned and cultivated in that year, and cultivated but remained fallow every year since then. The areas and slope degree were slightly different between the two plots, the cultivated one with area of 995.2 m^2 and average slope degree of 26º, and the control one, the forestland plot with area of 965.8 m^2 and average degree of 24.3º (Fig.1). Soil samples have been taken in the three zones (top, middle and bottom) within the plots. The runoff and sediment yield have been observed and the rainfall has been recorded. An introduction to structural indicators of soil quality, and their relationship to soil function and measuring methods were described in Table 1.

Fig. 1 Natural runoff plots for monitoring the influence of cultivation on soil properties with concern of soil erosion. (a) cultivated fallow land plot with area of 995.2 m^2 and average slope degree of 26º ; (b) natural forest plot with area of 965.8 m^2 and average degree of 24.3º, the main vegetation species are *Q. liaotungensis, P. tabulaeformis Carr., P. davidiana, B. platyphyllum, S. viciifolia, O. davidiana, Z. guguba, A. gmelinii,* and *P. betulaefolia Bge*

Table 1 Introduction to structural indicators of soil quality, their relationship to soil function and measuring methods

Structural indicators	Relationship to soil function	Measuring methods
Depth of topsoil	Soil organic matter (SOM), fertility, nutrient retention	Surface-down depth till the SOM is less than 1%
Porosity	Retention and transport of water and nutrients	Porosity (%) = (1-bulk density/particle density) × 100 (Head, 1980)
Aggregate stability	Infiltration, anti-erosion,	Turbidimetric method (Williams *et al.*, 1966)
Composition of porosity	Transport of water and nutrients	Micromorphology with computer image processing (He, 1997)

Samples for micromorphological analysis was impregnated with methylacrylate (He, 1998). Under a light microscope (LEICA LABORLUX 12), the area percentages of voids on thin sections were measured by the Quantiment 500, a microscopy-based computer image processing system (He, 1997).

4 Results and discussion

The observation data show that all soil properties have changed greatly since the forest vegetation was cleaned and the land was cultivated (Table 2). After 10 year cultivation, the soil organic matter in the topsoil decreased from 5.921% to 0.842%; soil bulk density increased from 0.65Mg • m^{-3} to 1.04Mg • m^{-3}; and aggregate stability declined from 73.84% to 28.21%. In fact, because the forest vegetation cover was destroyed and the root system was decomposed after 10 year cultivation, the soil was more susceptible topsoil erosion, leading the topsoil completely depleted (Tang *et al*., 1994). If this is true, about 60cm-depth topsoil had been depleted by soil erosion. Micromorphological investigation on thin sections show that in the sub-topsoil (at a depth of 20cm—40cm) of forestland, micromorphological features were dominated by small granular and subangular structures, voids of earthworms or roots, a number of micro-aggregates and abundant pore space (Fig.2). The statistic data of area percentage of pore space show that, in the topsoil of forestland, the macro-pore (>0.1 mm) space accounts for 12% and moderate pore (0.1—0.01) space accounts for 39.2% of the total pore space (Table 3). In the topsoil (at a depth of 20cm—30cm) of 10 year cultivated land, the micromorphological features are characterized by very fine granular structure with groundmass of silasepic and abundant secondary calcium carbonate (Fig.2b). According the statistic data of area percentage of pore space on thin sections, the macro-pore space and moderate pore space account for 8.9% and 24.2% of the total pore space in the topsoil of 10 year cultivated land, respectively. Compared with the forestland, the macro- and moderate pore space in the 10 year cultivated land had decreased by about 26% and 38% (Table 3), respectively.

Table 2 Comparison of soil properties before and after forestland cultivation (observed in 1999)

Depth (cm)	Organic matter (%)	Bulk density (Mg • m^{-3})	Aggregate stability (>0.25 mm) (%)
Forestland			
0—20	5.921	0.65	73.84
20—40	3.653	0.86	61.20
40—60	1.459	1.01	53.72
60—80	0.885	1.21	24.79
80—100	0.563	1.26	14.58
10 year cultivated fallow land			
0—20	0.842	1.04	28.21
20—40	0.567	1.24	19.11
40—60	0.502	1.26	14.74
60—80	0.392	1.29	13.31
80—100	0.393	1.29	13.55

Table 4 shows that after 10 years cultivation, the 60cm-depth of topsoil had been completely depleted; soil porosity indicator had decreased by 69% and macro-pore space, by 26%. All the soil structural indicators imply the soil quality has greatly declined because the vegetation destroyed and the land cultivated. As soil erosion was concerned, because of the decline of soil anti-erosion ability, soil erosion rate was only 2.21 ton • km^{-2} • a, but 14,800 ton • km^{-2} • a in the 10 year cultivated land.

Table 3 Changes of soil porosity composition before and after forestland cultivation (data are statistic area percentage in thin sections)

Depth (cm)	Porosity composition (%)		
	Macro-pore (>0.1 mm)	Moderate pore (0.1 mm—0.01 mm)	Micro-pore (<0.01 mm)
Forestland			
20—30	12.0	39.2	48.8
40—60	9.1	34.6	56.3
80—100	4.6	26.7	68.7
10 year cultivated fallow land			
20—30	8.9	24.2	66.0
40—60	5.0	27.2	67.8
80—100	3.5	29.8	66.7

Table 4 Soil structural indicators and their links to the soil erosion rate

Soil structural indicators				Soil erosion rate ton/(km^2 • a)
Depth of topsoil[1] (cm)	Porosity[2] (%)	Aggregate stability (>0.25) (%)	Macro-pore (>0.1 mm) (% of the total pore space)	
Forestland				
60	57.20	61.20	12.0	2.21
10 year cultivated fallow land				
0	47.45	19.11	8.9	14800

[1]the surface-down depth till the organic content is less than 1%

[2]calcaluted by: Porosity=(1-bulk density/particle density)×100

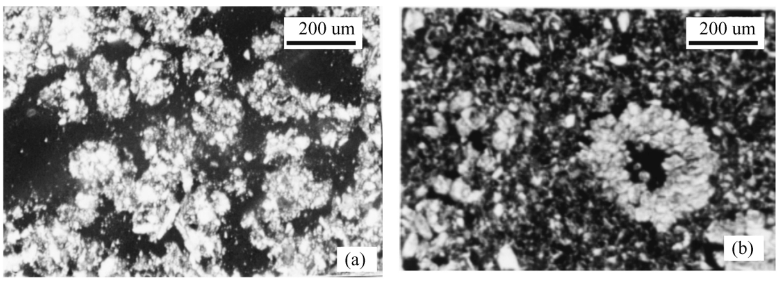

Fig. 2 Photomicrographs of typical micromorphological features at a depth of 40 cm in forestland (a) and 10 year cultivated fallow land (b) (crossed polarized light; scale *bar*=200μm). (a) micro-aggregates in void; (b) calcitic coating on the wall of a void

5 Conclusion

Soil structure is a base for its ecological function and sensitive to environmental disturbance, especially in the areas where soil material is chemically homogeneous. The present study area, the Ziwuling loess hilly-gully area is such a region with severe problem of soil erosion. Soil erosion is the main cause of land degradation. Results show that after 10 years cultivation, the 60cm-depth of topsoil had been completely depleted; other structural indicators decreased by at least 25%. Soil erosion rate in the 10 year cultivated land was a thousand times of that in the forestland. It implies that soil structural indicators were a sensitive proxy indicator for soil quality in that region.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (49901012). The authors express sincere thank to Prof. Zhao Jingpuo for assistance in thin section preparation, Mr. Cha Xiaochun for help in field investigation and sampling.

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