

Soil Quality Degradation Processes along a Deforestation Chronosequence in the Ziwuling Area, China

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Abstract

Utilization of soil resources on the Loess Plateau of Northwestern China. We studied the physical, chemical Accelerated erosion caused by deforestation and soil degradation has become the primary factor limiting sustainable, and microbiological processes of soil degradation along a chronosequence of deforestation in the Ziwuling area of northwestern Shaanxi province. The results indicated that soil wet aggregate stability, mean aggregate diameter decreased with years following deforestation. Accelerated erosion resulted in soil nutrient loss, and a decrease in soil enzyme activities including notable losses of total soil N, organic C, alkaline phosphatase activity, and invertase activity. During the early time period, the rates of total soil N, organic C, alkaline phosphatase activity, and invertase activity decreasing were rapid and gradually decreased with deforestation years. Increased use of nitrogen fertilizers made determination of soil quality based on measured NO₃-N and NH₄-N inconclusive. The differences in measured parameters between the topsoil and subsoil horizons decreased with time since deforestation, soil erosion was the primary process responsible for the degradation of measured soil physical, chemical, and microbiological properties.

Keywords: Accelerated erosion; Deforestation; Soil quality; Loess Plateau; Soil enzyme activities; Wet aggregate stability

1. Introduction

Loess plateau ecosystems have been affected by various forms of human activity for millennia (Wang, 2002). It is widely held that forest clearance for agriculture as practiced on the Loess Plateau, decreases biodiversity, limits the naturally adapted vegetation, and simplifies the ecosystem structure (Li et al., 2005). The impacts of human activity on the Loess Plateau have been characterized as continuous and widespread stresses such as over-grazing and large scale monocultures of wheat and maize (Fu et al., 2000). Zheng (2005) reported that about 70 % of the total area of the Loess Plateau is affected by moderate to severe soil erosion. Soil erosion rate estimates range from 5000 to 25000 Mg ha⁻¹ yr⁻¹ (Fu et al., 2005) on the Loess Plateau.

Although the literature is replete with information about the degradation of soil quality factors following deforestation, little information exists concerning the effects of accelerated erosion on soil quality degradation processes following deforestation in the Loess Plateau. This investigation was initiated to elucidate the effects of deforestation and the resultant accelerated erosion on soil properties at this location.

2. Materials and Methods

2.1. Study Site Description

Natural climax vegetation has been destroyed over the last century or so except in the Ziwuling area between the boundary of northwestern Shaanxi province and Gansu province. The Ziwuling forest area occupies approximately 23,000 km² and is the sole secondary forest region remaining on the Loess Plateau. The study area lies within N (36°03'35"-36°05'26") and E (109°08'57"-109°10'53") in the hilly-gully region between the Dongzhi and Luochuan Plateaus. Before about 1866-1870, the eco-environment of the Ziwuling region was similar to most regions of the hilly-gully region on the Loess Plateau; the natural vegetation had been completely destroyed and soil erosion was severe. At about that time, a war between competing tribal units resulted in population decrease and wide-spread exodus from the area. At the time of the exodus, anthropogenic influences ceased and a secondary growth of forest species began developing (Tang et al., 1993; Zheng et al., 1997).

2.2. Soil Sampling and analysis

In general, the land managers of the farms (sites) selected for this study have used very similar methodologies and crops. The time sequence and characteristics of the sites are described in Table 1. From each

site, we obtained three replicate samples of 15 cm × 20 cm from the 0 – 20 cm depth and the 20 – 40 cm depth at each replicate sampling location. Soil physical and chemical properties were determined according to the standard methods using the methodology prescribed by the Institute of Soil Science of the Chinese Academy of Science (1981). Invertase activity was measured using titration method. Urease activity was determined by a colorimetric technique. Alkaline phosphatase activity was determined by colorimetry as described by (Guan et al., 1991)

2.3 Statistical Analysis

The chronosequence dependent effects on soil properties were analyzed using least squares regression procedures available in SPSS v.11.5. The regression models were forced through the origin as it was assumed that no change had occurred at t_0 . Triplicate soil samples and extracts allowed estimation of the standard errors for each analysis.

3. Results

3.1 Deforestation effects on soil physical properties

The mean weight diameter (MWD) of water stable aggregates (WSA) and the percentage of water stable aggregates in the larger diameter classes decreased with deforestation in cultivation (Table 2). The largest three size classes (> 5 mm, 2 – 5 mm, and 1 – 2 mm) decreased most sharply as the secondary forest soil was characterized by 32.0%, 11.9%, and 10.6% of the WSA being in the >5 mm, 2 – 5 mm, and 1 – 2 mm diameter classes, respectively. For the secondary forest soil, more than half the WSA were >1 mm in diameter, in contrast to 0.0%, 4.6%, and 6.3%, totaling less than one eighth, for the >5 mm, 2 – 5 mm, and 1 – 2 mm diameter classes, respectively in the soil with a 100 year cultivation history. The next smaller WSA diameter class, 0.5 – 1 mm, was apparently unaffected by time in cultivation. The 0.25 – 0.5 mm diameter class was observed to increase with years in cultivation as was the <0.25 mm size class. Thus as the larger WSA degraded, the smaller diameter WSA increased from 33.9% in the secondary forest soil to 76.7% in the soil that had been cultivated for 100 years.

3.2 Deforestation effects on soil chemical properties

Following deforestation, SOC and TN decreased as a power function of years cultivated (Fig. 2). In the 0 – 20 cm layer, SOC content decreased an average of 26.6%, 42.8%, 45.4%, 72.3%, 77.5%, 73.6%, 83.3%, and 84.4% following 4, 9, 12, 33, 43, 52, 75, and 100 years of cultivation, respectively. In the plots representing 100 years of cultivation, SOC was found to be only 4.94 g kg⁻¹ compared to 23.21 g kg⁻¹ for the secondary forest soil. During the same time period, TN decreased to 0.51 g kg⁻¹ compared with 2.16 g kg⁻¹ for the secondary forest soil. The rates of SOC and TN degradation apparently decrease with time in cultivation. In the 0 – 20 cm surface horizon, the initial (0 – 4 yr) rates of SOC and TN decrease are 1.54 g kg⁻¹ yr⁻¹ and 0.10 g kg⁻¹ yr⁻¹, respectively. These initially high rates of SOC and TN decrease drop to 0.62 g kg⁻¹ yr⁻¹ and 0.06 g kg⁻¹ yr⁻¹, respectively, for years 4 – 9 and to 0.27 g kg⁻¹ yr⁻¹ and 0.03 g kg⁻¹ yr⁻¹, respectively for years 9 – 33. Apparently, after 33 years of cultivation, the SOC and TN contents are largely depleted, subsequent degradation rates become very small, and the soil approaches a quasi-equilibrium of SOC and TN content based on the management practices employed. From figure 2d, one can see that the NO₃-N content of both soil horizons also decreases as years in cultivation increase. This decrease is very steep in the early years of the chronosequence, but apparently slows sometime after year 12. Following 100 years of cultivation, soil NO₃-N contents are only 3.25 mg kg⁻¹ and 0.88 mg kg⁻¹ for the 0 – 20 cm and 20 – 40 cm horizons, respectively. Time in cultivation did not seem to affect the NH₄-N or P contents of the soils studied.

3.3 Deforestation effects on soil enzyme activities

The activities of urease in the upper 20 cm of secondary forest soil were 205.4 NH₃-N mg 100g⁻¹ 24hr⁻¹ compared to highest contents in 12 years farm land. Noted for the 20 – 40 cm soil horizon were 45.8 mg NH₃-N 100g⁻¹ 24hr⁻¹ compared to highest contents in 9 years cropland. During the initial 12 years following deforestation, the activities of urease was observed to be increased after which they tended to decline over time. It is expected that the activities of this enzyme would increase as increased aeration and soil temperatures caused by cultivation would result in increased microbial activity and organic matter oxidation. By contrast, invertase and alkaline phosphatase were most active under the secondary forest, and changed little during the initial 12 years following deforestation and then declined to a level that fluctuated, but showed no clear time-dependent trends in content.

4. Discussion

4.1 Deforestation effects on soil physical properties

The initial increase of soil erosion is almost certainly due to the removal of the canopy and surface litter that protects the soil surface from the energy of raindrop impact and surface detachment. As evidenced from the initial 3 order of magnitude increase, it is obvious that surface cover is probably the greatest single management effect on soil erosion and this effect is documented well in the literature (Nearing et al., 1994). Native structure is destroyed by the plow and the stabilizing effects of root fibers become insignificant as the roots are shredded by the tillage microbially decomposed following deforestation. As pore space increased due to the mechanical cultivation, the air exchange increased the available oxygen for microbial decay of organic matter, particularly the particulate organic matter (POM) that is highly effective at binding soil particles (Wei et al., 2006). This factor, coupled with the accelerated erosion rapidly depleted the SOM in the plow layer and weakened the soil WAS (Zhang and Horn, 2001).

4.2 Deforestation effects on soil enzyme activities

There is a growing interest in soil quality indicators that can be used as early indicators of directional change. In this study, soil enzyme activities were closely related to changes in SOM and TN, which showed also a decrease following deforestation. This observation is in agreement with Nourbakhsh (2006) who reported that decreasing levels of SOM are responsible for lesser contents of bio-indicators in deforested soils. Soil enzyme activities play an important role to soil nutrient cycling and in the degradation of organic inputs, and thus can be useful for indicating the degree of biochemical processes in soil (Bandick et al., 1999; Acosta-Martinez et al., 2003). In a manner similar to the degradation noted for soil nutrient status and soil structure, soil enzyme activities were also significantly ($P < 0.05$) reduced by years in cultivation following deforestation (Fig. 3). At the Ziwuling area, enzyme activities changed very quickly in the first few years following deforestation. It is apparent that sometime after the twelfth year following deforestation, the microbial dynamics of the system changed significantly and come to a quasi-equilibrium with the cultivation management system. The sharp decline noted for the site representing 33 years since deforestation may be a site dependent phenomenon as the quasi-equilibrium noted for the sites representing later stages in the chronosequence have greater activities of all three soil enzymes.

Conclusions

From visual observations at the Ziwuling area on the Loess Plateau, the soil erosion changes from primarily sheet erosion typical of the forested sites to intense rill and gully erosion in the first few years following deforestation. The MWD of soil aggregates decreases rapidly after 12 deforestation years, so as to SOM, TN, $\text{NO}_3\text{-N}$ and soil enzyme activities. By 33 years following deforestation, these soil quality parameters are apparently approaching a content that is in quasi-equilibrium with the management system.

There is no clear cause and effect mechanism between soil degradation processes and erosion at the Ziwuling area. It is apparent that considerable SOM and nutrients are lost from the plow layer due to erosion following deforestation, but it is equally apparent that microbially induced decomposition of POM and other SOM increases runoff, reduces the binding agents of soil particles, and ultimately results in increased soil erodibility. What is important is that at the Ziwuling area, and similar locations on the Loess Plateau of China, erosion is a soil degrading process that greatly exacerbates the microbial decomposition of SOM that is typically the primary process leading to soil quality degradation following deforestation. Best management practices that maintain soil quality and reduce erosion must be developed for this region to remain productive.

Acknowledgement

This study was funded by National Basic Research Program of China(2007CB407201), National Natural Sciences Foundation of China(40701095) and the Innovation Team Plan of Northwest A & F University (01140202).

Table 1 General situation of sampling sites with different deforestation years

Site No.	Deforested years	Slope aspect	Slope (°)	Elevation (m)	Fertilizer application of 2005 (kg/m ² .a)			Rotation		
					N	P ₂ O ₅	K ₂ O	2003	2004	2005
1	Forest soil	S	14□32	1244	0	0	0	—	—	—
2	4	ES 52	6□14	1231	0	0		Millet	Bean	Red bean
3	9	WS11	8□25	1256	0	0		Bean	Rape	Millet
4	12	S	13□17	1257	15.8	18.1	16.9	Millet	Red bean	Rape
5	33	WS	8□21	1312	16.0	11.2	0	Corn	Millet	Bean
6	43	S	8□18	1288	11.2	12.8	12.0	Bean	Wheat	Bean
7	52	S	3□13	1245	22.3	25.5	23.9	Wheat	Bean	Red bean
8	75	S	3□7	1252	18.4	21.0	19.7	Corn	Corn	Bean
9	100	ES10	5□7	1296	42.7	30.0	0	Wheat	Red bean	Rape

Table 2 Soil water-stable aggregates in 0-20cm depth in the forest soils and the arable soils by years following deforestation (mean values and standard deviation are shown, n=3, different letters indicate significant differences at p<0.05)

Deforested year (a)	Composition of different size aggregates %						MWD
	>5 mm	5-2 mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	>0.25 mm	
Forest soil	32.0±6.2 a	11.9±2.2 ab	10.6±3.3 abc	11.6±2.7 abc	5.1±0.3 c	71.2±1.5 a	2.4±0.3 a
4	23.7±10.7 abc	11.4±2.9 ab	14.2±2.1 a	13.6±1.0 a	8.4±0.6 b	71.3±2.7 a	2.0±0.4 ab
9	31.1±3.7 ab	8.1±1.4 bcd	10.4±1.1 abc	10.8±0.9 abc	6.6±0.5 bc	67.0±1.3 a	2.2±0.2 a
12	28.4±25.2 ab	13.9±5.8 a	11.3±6.4 ab	8.1±4.0 c	6.2±2.3 c	67.9±3.7 a	2.2±0.9 a
33	10.5±2.2 cd	8.5±1.1 bcd	10.1±1.3 abcd	13.6±0.5 a	11.3±1.3 a	54.0±0.8 b	1.23±0.1 c
43	14.8±6.4 bcd	10.7±1.3 abc	8.1±2.4 bcd	8.8±1.4 bc	8.3±1.2 b	50.7±1.4 bc	1.5±0.2 c
52	16.3±11.1 abcd	5.6±1.2 d	5.6±2.2 d	10.0±3.2 abc	11.1±2.4 a	48.5±1.8 bc	1.3±0.4 c
75	3.6±5.5 d	7.1±4.1 cd	9.5±2.5 bcd	13.7±2.0 a	12.9±1.1 a	46.9±2.2 c	0.9±0.1 cd
100	0.0±0.0 d	4.6±0.5 d	6.3±0.6 cd	12.4±3.9 ab	12.6±0.9 a	35.9±1.7 d	0.6±0.0 d

MWD is “mean weight diameter of soil aggregates”

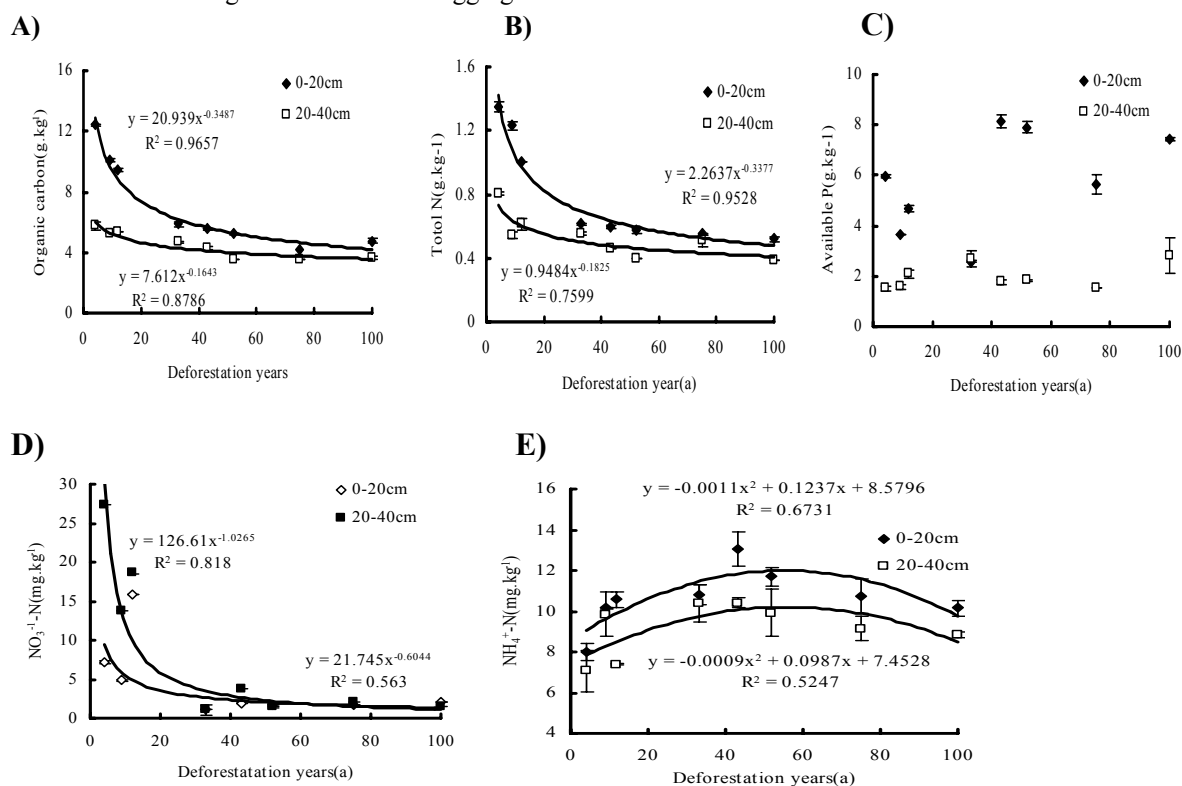


Figure 1 Changes in soil organic carbon (A), Total N (B), Available P (C), NH₄⁺-N (D) and NO₃⁻-N (E) contents following deforestation

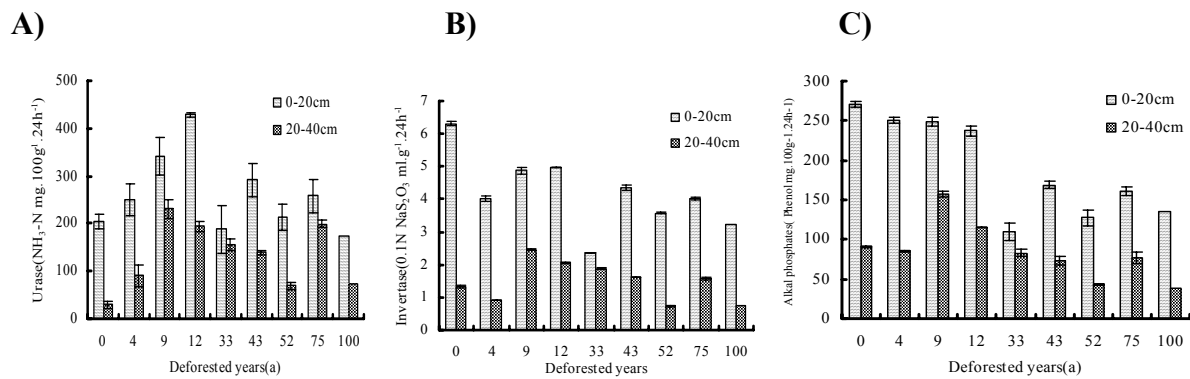


Figure 2 Change of soil enzyme activities by years following deforestation

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