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# SOIL QUALITY EVALUATION DURING VEGETATION RECOVERY AT HILL SLOPES WITH PURPLE SOIL IN HENGYANG, CHINA

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*Key words*: Soil quality, Evaluation, Purple soil

## Abstract

To investigate the effect of vegetation recovery on soil quality at hill slopes with purple soil in Hengyang, China, 4 typical sample plots with vegetation recovery chronosequence, i.e. grassplot (GT) (2 a), frutex and grassplot (FG) (5-8 a), frutex (FX) (20-25 a), arbor and frutex (AF) (approximately equal to 50 a), with basically similar site conditions, were selected as test objects. The comprehensive index of soil quality was applied to investigate the changes of soil quality in the process of vegetation recovery. As vegetation recovery proceeded from GT to FG, FX and AF, soil quality improved significantly ($p < 0.05$). As soil depth increased, the degree of soil quality improvement decreased significantly ($p < 0.05$). The comprehensive indexes of soil quality in various stages of vegetation recovery showed a decreasing pattern: AF (0.527), FX (0.519), FG (0.483), GT (0.481). All the results indicated vegetation recovery significantly improved the soil quality of hillslopes with purple soil in Hengyang of Hunan province, China.

## Introduction

Soil quality is the capability of soil to maintain biological production, protect environmental quality, and promote the health of animals and plants, and an indicator of the physical, chemical, and biological properties of soil. As the most sensitive index of changes in soil, soil quality can reveal not only the level of soil management but also the capability of soil recovery (Gil-Sotres *et al.* 2005). Appropriate land utilization measures can improve soil quality and resistance to soil disturbance; however, unreasonable measures can destroy aggregate soil structure, accelerate soil erosion, and reduce soil productivity (Ramos *et al.* 2010). Therefore, the establishment of an indexing system for soil quality evaluation is significantly meaningful to the evaluation (Liu *et al.* 2008).

The land area of hill slopes with purple soil in Hengyang is located in the central south of Hunan province, China and along the middle reach of Xiangjiang River (geographical coordinates: 11°032′ 16″ - 13° 16′ 32″ E, 26° 07′ 05″ - 27° 28′ 24″ N) with the area of $1.625 \times 10^5$ $hm^2$. Its ecological environment is very poor (Yang *et al.* 2013). However, previous studies on the ecosystem degradation of this region focused on the physico-chemical properties of soil, and could not make the overall assessment on the soil quality well (Xie and He 2005, Yang *et al.* 2012). Therefore, the effects of vegetation recovery and succession on soil quality in this region should be investigated. In this study, the substitution of time sequence with spatial sequence (Kent and Coker 1992) was applied to investigate the physical, chemical, and biological properties of soil in various stages of vegetation recovery. Soil quality was evaluated comprehensively and reasonably to develop a strategy that can be implemented to improve soil quality. This study also provided a scientific basis for the ecosystem recovery of the similar hill slopes with purple soil.

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## Materials and Methods

The research site is located in the Tanzishan Town, Hennan County of Hunan province, China, about 25 km to the east downtown of Henyang. The area is 4907 $hm^2$. The main geomorphic type of the study site is hilly, and the purple soil is dominant, accounting for about 95%. The soil of most of the hill slope is shallow, and mother rocks are exposed in the air, which brings in great difficulties to plant trees and grass. The climate is mild and humid, suitable for the growth of a variety of forest and crop, but the drought and high temperature during the summer and the autumn has a negative impact on the production of agriculture, forestry and animal husbandry.

Four standard sample plots were selected on the basis of local data in September and October 2013. There were abandoned lands in early succession, greater than 1 $hm^2$ each. The plots represented different recovery stages (Table 1) namely, grassplot stage (GT), frutex and grassplot stage (FG), frutexstage (FX), and arbor and frutexstage (AF). Three standard quadrats were set in each sample plot; adjacent quadrats were separated at a distance of more than 20 m. The soil at 0 - 20, 20 - 40, and 40 - 60 cm depths were sampled. The soil samples from the same quadrat and the same depth were mixed in equal proportion to obtain one sample. This process was repeated thrice. The soil samples were divided into two parts. One part was air-dried and screened using a 2 mm sieve to determine the soil physicochemical properties. The other part was also screened using a 2 mm sieve and stored at 4°C in a refrigerator until the soil biological properties were determined.

**Table 1. General information of the standard sample plots.**

| Recovery stage | Years of recovery (a) | Slope position | Gradient/ direction (°/) | Altitude (m) | Coverage (%) | Soil type | Dominant plant |
|---|---|---|---|---|---|---|---|
| GT | 2 | Lower-middle slope | 25/SW | 125 | 35 | Purple soil | *Setaria viridis* (*SV*); *Cynodon dactylon* (*CD*) |
| FG | 5 - 8 | Lower-middle slope | 20/SW | 115 | 45 | Purple soil | *Lagerstroemia indica* (*LI*); *Abelia chinensis* (*AC*); *SV* |
| FX | 20 - 25 | Lower-middle slope | 30/SW | 120 | 60 | Purple soil | *Vitex negundo* var. *cannabifolia* (*VNVC*); *Robinia pseudoacacia* (*RP*); *AC*; *Serissa japonica* (*SJ*) |
| AF | ~50 | Lower-middle slope | 25/SW | 130 | 80 | Purple soil | *Liquidamdar formosana* (*LF*); *Melia azedarach* (*MA*); *VNVC* |

Integrated fertility indexes (IFI) are the comprehensive indication of the physical, chemical, and biological properties of soil, including: (1) physical property indexes: soil water content (SWC), bulk density (BD), and soil electric conductivity (SEC) which is measured according to the reference (Bao 2000); (2) chemical property indexes: soil organic matter (SOM), total nitrogen (TN), nitrate-nitrogen in the soil ($NO_3^-$-N -N), available phosphorus (AP), and available potassium (AK). The indexes were measured according to the reference (Bao 2000); (3) biological property indexes: soil microbial biomass carbon (SMBC), and soil microbial biomass nitrogen (SMBN). The indexes were measured according to the references (Vance *et al.* 1987, Sparling *et al.* 1993).

The degrees of membership of SBD and SEC were determined using function (1); the degrees of membership of the other factors were identified using function (2) (Liu *et al.* 2006):

$$F(X) = (X_{man} - X)/(X_{max} - X_{min}) \quad (1)$$

$$F(X) = (X - X_{min})/(X_{max} - X_{min}) \quad (2)$$

where $F(X)$ is the degree of membership of each soil factor, X is the value of each soil factor, and $X_{max}$ and $X_{min}$ are the maximum and minimum values of each soil factor, respectively.

The importance of each factor was represented with a weight coefficient because of the differences in the relative importance of the soil factors. Through principal component analysis (PCA), the weight of each soil factor in soil quality evaluation was calculated (Sant′anna *et al.* 2009).

$$W_i = CC_i / \sum_1^n (CC_i) \quad (3)$$

where $W_i$ is the weight of each soil factor and $CC_i$ is the loading of the $i^{th}$ soil factor.

Calculation of the comprehensive index of soil quality (Deng 1987) using function (4).

$$ISQII = \sum_{i=1}^{n} W_i \cdot F(X_i) \quad (4)$$

where $W_i$ is the weight and $F(X_i)$ is the degree of membership of each soil factor.

The experimental data used the means of three repetitions as the statistical units, and all the data were represented with the standard deviation. Data were processed and analyzed using SPSS13.0. One-way ANOVA were applied to analyze the variance, and the least significant difference to test the significance of differences at $\alpha = 0.05$.

**Results and Discussion**

Table 2 shows that SWC in each soil layer (0 - 20, 20 - 40, and 40 - 60 cm) increased significantly ($p < 0.05$) as recovery progressed; by contrast, SBD and SEC decreased significantly ($p < 0.05$). The SOM contents increased significantly ($p < 0.05$) as recovery progressed in the 0 - 20 cm soil layer. The respective SOM contents in stages FX, FX, and AF were 1.53, 1.77, and 3.80 times higher than the SOM content in stage GT. The SOM content in the 20 - 40 cm soil layer showed the following decreasing pattern: AF, FG, FX, and GT ($p < 0.05$). The SOM content in all of the stages decreased significantly ($p < 0.05$) as the soil depth increased.

As vegetation recovery proceeded, the TN contents in this soil layer in the four recovery stages exhibited a decreasing pattern: FX, AF, GT, FG ($p < 0.05$). The $NO_3^-$-N contents in stages FX and AF were significantly higher than those in stages GT and FG ($p < 0.05$). The TN and $NO_3^-$-N contents decreased significantly ($p < 0.05$) as the soil depth increased in all of the recovery stages. In the 40 - 60 cm soil layer, the AP content in stage AF was significantly higher than those in the other recovery stages ($p < 0.05$). Moreover, the AP content decreased significantly (with $p < 0.05$) as soil depth increased in all of the recovery stages.The AK content in stage AF was significantly lower than those in the other recovery stages ($p < 0.05$). In the 40 - 60 cm soil layer, the AK content increased significantly ($p < 0.05$) as recovery progressed. The AK content also decreased significantly ($p < 0.05$) as soil depth increased in all of the recovery stages.

Table 3 shows that the SMBC and SMBN contents increased significantly ($p < 0.05$) in the three soil layers (0 - 20, 20 - 40 and 40 - 60 cm) as recovery progressed. For example, the SMBC contents in stages FG, FX, and AF were 1.33, 2.04, and 2.89 times that of the contents in stage GT in the 0 - 20 cm soil layer, respectively. The SMBC and SMBN contents decreased significantly ($p < 0.05$) as soil depth increased in all of the recovery stages.

**Table 2. Physico-chemical properties of soils in different vegetation recovery stages.**

| Physico-chemical properties | Soil layer (cm) | Recovery stage | | | |
|---|---|---|---|---|---|
| | | GT | FG | FX | AF |
| Soil water content (g/kg) | 0 - 20 | 146.09±13.23 Aa | 186.34±12.45 Ba | 236.00 ± 17.45 Ca | 326.98±27.65 Da |
| | 20 - 40 | 132.34±11.09 Ab | 165.87±15.89 Bb | 224.67±20.64 Cb | 316.98±29.79 Db |
| | 40 - 60 | 118.76±10.76 Ac | 153.78±10.54 Bc | 200.54±18.37 Cc | 214.65±15.54 Dc |
| Soil bulk density (g/cm) | 0 - 20 | 1.13±0.23 Aa | 1.11±0.16 Aa | 1.06±0.21 Ba | 0.98±0.12 Ca |
| | 20 - 40 | 1.27±0.18 Ab | 1.21±0.13 Ab | 1.12±0.16 Bb | 1.10±0.11 Bb |
| | 40 - 60 | 1.36±0.20 Ac | 1.28±0.24 Bc | 1.20±0.19 Cc | 1.16±0.17 Cc |
| Soil electric conductivity (mS/cm) | 0 - 20 | 1.45±0.10 Aa | 1.34±0.14 Ba | 1.12±0.12 Ca | 1.09±0.09 Da |
| | 20 - 40 | 1.49±0.09 Aab | 1.40±0.10 Bab | 1.36±0.13 Bb | 1.18±0.10 Cab |
| | 40 - 60 | 1.52±0.12 Ab | 1.47±0.11 Ab | 1.39±0.08 Bc | 1.27±0.15 Cb |
| Soil organic matter (g/kg) | 0 - 20 | 15.43±1.09 Aa | 23.56±2.00 Ba | 27.34±2.64 Ca | 58.65±4.21 Da |
| | 20 - 40 | 12.85±2.38 Ab | 15.48±1.43 Bb | 13.65±1.30 Cb | 17.76±1.75 Db |
| | 40 - 60 | 11.37±1.94 Ac | 16.96±1.67 Bc | 11.45±1.05 Ac | 12.31±2.46 Cc |
| Total nitrogen (g/kg) | 0 - 20 | 0.69±0.04 Aa | 0.58±0.03 Ba | 0.78±0.03 Ca | 0.87±0.08 Da |
| | 20 - 40 | 0.39±0.02 Ab | 0.44±0.04 Bb | 0.66±0.05 Cb | 0.59±0.04 Db |
| | 40 - 60 | 0.24±0.02 Ac | 0.25±0.02 ABc | 0.26±0.02 Bc | 0.42±0.02 Cc |
| $NO_3^-$-N (mg/kg) | 0 - 20 | 6.54±1.45 Aa | 6.86±1.43 Ba | 7.65±1.67 Ca | 8.75±1.70 Da |
| | 20 - 40 | 6.09±1.65 Ab | 6.23±1.54 Ab | 7.67±1.69 Ba | 7.57±1.54 Bb |
| | 40 - 60 | 3.76±1.79 Ac | 5.76±0.98 Bc | 5.56±1.54 Bb | 6.88±1.66 Cc |
| Available phosphorus (mg/kg) | 0 - 20 | 7.78±0.76 Aa | 8.65±0.59 Ba | 9.28±0.38 Ca | 9.67±0.24 Ca |
| | 20 - 40 | 5.12±0.60 Ab | 4.69±0.76 Bb | 7.17±0.67 Cb | 6.85±0.25 Db |
| | 40 - 60 | 2.60±0.46 Ac | 3.98±0.58 Bc | 3.67±0.61 Bc | 5.76±0.37 Cc |
| Available potassium (mg/kg) | 0 - 20 | 361.11±8.45 Aa | 345.54±6.12 Ba | 361.08±18.54 Aa | 298.45±8.37 Ca |
| | 20 - 40 | 185.03±10.65Ab | 180.55±7.45 Ab | 189.44±12.43 Ab | 160.65±9.47 Bb |
| | 40 - 60 | 135.36±6.60 Ac | 147.12±7.06 Bc | 155.57±8.54 BCc | 159.54±10.65 Cb |

Different capital letters in the same row and different small letters in the same column meant significant difference of the same soil physico-chemical properties for different vegetation restoration stages and for different soil layers at 0.05 level, respectively. The same as below.

The original experimental data of the soil quality factors characterized in terms of eight physical and chemical factors and two soil microbial biomass indexes were processed to become nondimensional; the degree of membership of each factor was obtained (Table 4). The PCA (Fox and Melta 2005, Tian *et al.* 2012) results of the degree of membership of each evaluation factor (Table 5) revealed that the accumulative contribution rates of variance and the eigenvalues of the first three principal components were PC1 (64.24, 6.932), PC2 (21.05, 2.263), and PC3 (14.79, 1.592). In PC1, soil BD, organic matter content, TN, and $NO_3^-$-N showed a high factor loading of >0.900. Among these factors, soil BD yielded the largest negative loading (−0.993). In PC2, the factor loadings of EC, AP, and AK were 0.887, 0.886, and 0.845, respectively. In PC3, SMBC and SMBN exhibited high factor loadings of 0.785 and 0.768, respectively. Likewise, the following soil quality factors displayed a decreasing pattern on the basis of their relative weight: SMBC (0.132), SMBN (0.119), BD (0.109), AP (0.124), SWC (0.098), $NO_3^-$-N -N(0.095), TN (0.084), content of organic matter (0.066), AK (0.056), and EC (0.054). Therefore, SMBC, SMBN, BD, AP, and SWC greatly influenced the soil quality.

**Table 3. Soil microbial biomass carbon and nitrogen contents in different vegetaion recovery stages.**

| Soil microbial biomass | Soil layer (cm) | Vegetation recovery stage | | | |
|---|---|---|---|---|---|
| | | GT | FG | FX | AF |
| Soil microbial biomass carbon (mg/kg) | 0 - 20 | 350.12±27.09 Aa | 465.76±30.00 Ba | 712.65±43.09 Ca | 800.97±50.65 Da |
| | 20 - 40 | 267.43±19.65 Ab | 367.09±29.87 Bb | 600.16±54.12 Cb | 754.32±48.56 Db |
| | 40 - 60 | 175.94±14.09 Ac | 274.16±25.06 Bc | 487.67±32.07 Cc | 631.47±54.73 Dc |
| Soil microbial biomass nitrogen (mg/kg) | 0 - 20 | 36.98±3.00 Aa | 48.45±5.76 Ba | 50.12±4.89 Ca | 75.54±5.31 Da |
| | 20 - 40 | 35.33±4.00 Aab | 39.34±3.87 Bb | 42.38±4.05 Cb | 45.43±3.96 Db |
| | 40 - 60 | 34.87±2.08 Ab | 35.64±3.56 Bc | 37.55±3.67 Cc | 40.00±4.19 Dc |

**Table 4. Soil properties and their membership value of different vegetation restoration stages.**

| Soil property | Vegetation recovery stage | | | |
|---|---|---|---|---|
| | GT | FG | FX | AF |
| Soil water content | 0.443 | 0.453 | 0.467 | 0.489 |
| Soil bulk density | 0.557 | 0.548 | 0.530 | 0.495 |
| Soil electric conductivity | 0.559 | 0.556 | 0.541 | 0.536 |
| Soil organic matte | 0.437 | 0.456 | 0.557 | 0.593 |
| Total nitrogen | 0.389 | 0.410 | 0.513 | 0.564 |
| $NO_3^-$-N | 0.456 | 0.504 | 0.604 | 0.712 |
| Available phosphorus | 0.438 | 0.440 | 0.495 | 0.505 |
| Available potassium | 0.398 | 0.400 | 0.387 | 0.415 |
| Soil microbial biomass carbon | 0.390 | 0.426 | 0.562 | 0.641 |
| Soil microbial biomass nitrogen | 0.431 | 0.453 | 0.547 | 0.668 |

The comprehensive indexes of soil quality in stages GT, FG, FX and AF calculated using Eq. (4) were 0.481, 0.483, 0.519, and 0.527, respectively. The comprehensive indexes in stages FG, FX and AF were greater than those in stage GT by 0.42%, 7.9%, and 9.56%, respectively. This result indicated that the comprehensive index of soil quality on the hill slopes with purple soil in Hengyang increased over the years as vegetation recovery proceeded.

Although the soil microbial biomass, one of soil indexes, only holds 1 - 3% of organic carbon and 3 to 6% of organic nitrogen, it plays a significant role in the nutrient circulation and energy flow of the soil ecosystem, and is associated almost with all the soil processes. Soil microbes can accelerate the changes of soil physical and chemical properties, and in the short term reflect sensitively the change of soil quality (Stern *et al.* 1992, Yu *et al.* 2003). As vegetation recovery proceeds in the hill slopes with purple soil in Hengyang of Hunan province, China, the increase in the amounts of litter falls and rhizosphere metabolite would lead to the increasing the input of SOM, which promoted soil microbial growth and the increase on soil microbial biomass. In GT, FG, FX, and AF recovery stages, soil microbial biomass decreases as soil depth increases (Table 3). This finding indicated that a large number of soil microbes exist in the surface soil layer; furthermore, these microbes is conducive to the decomposition of litter, and as a result, the rate of nutrition supply increases (Wardle 1998).

SWC increased significantly in terms of time, space, and soil physical and chemical properties as recovery proceeded; by contrast, soil BD and soil EC decreased significantly as recovery proceeded. As soil depth increases, SWC decreased significantly, but soil BD and EC increased significantly. This result indicated that vegetation recovery can improve soil quality (Chen *et al.* 2010). In addition, the increasing canopy density decelerates litter fall decomposition from GT, FG, FX to AF recovery stages. Thus, differences in nutrient contents in the surface soil would be more remarkable than those in the deep soil (Table 2) as the recovery proceeds. Also, those confirm that the interaction and mutil-influences between the soil physical and chemical properties and biological properties of soil ecological system can make the soil quality in the form of biological properties (Franchini *et al.* 2007, Richardson *et al.* 2009).

**Table 5. Principal component analyses (PCA) of soil quality.**

| Soil property | Twiddle factor loading of principal component | | | Weight |
|---|---|---|---|---|
| | PC1 | PC2 | PC3 | |
| Soil water content | 0.712 | 0.563 | −0.459 | 0.098 |
| Soil bulk density | −0.993 | 0.078 | 0.057 | 0.109 |
| Soil electric conductivity | −0.428 | 0.887 | 0.212 | 0.054 |
| Soil organic matter | 0.901 | −0.563 | 0.098 | 0.066 |
| Total nitrogen | 0.924 | −0.437 | 0.321 | 0.084 |
| $NO_3^-$-N | 0.978 | −0.189 | −0.099 | 0.095 |
| Available phosphorus | 0.135 | 0.886 | −0.056 | 0.124 |
| Available potassium | −0.428 | 0.845 | 0.275 | 0.056 |
| Soil microbial biomass carbon | 0.401 | 0.345 | 0.785 | 0.132 |
| Soil microbial biomass nitrogen | −0.453 | −0.216 | 0.768 | 0.119 |
| Eigenvalues of principal component | 6.932 | 2.263 | 1.592 | |
| Contribution rate of variance (%) | 64.23 | 21.00 | 14.77 | |
| Accumulative contribution rate (%) | 64.23 | 85.23 | 100.00 | |

The comprehensive evaluation on soil quality in various recovery stages can provide the basis of vegetation recovery in the region. The results indicated that the soil physical, chemical, and biological properties and the overall soil quality improved significantly as the vegetation recovery proceeded. Furthermore, the more progress of vegetation restoration, the more obvious the improvement of soil (Zhang *et al.* 2010). Therefore, in the ecological management of the hill slopes with purple soil in Hengyang of Hunan province, vegetation recovery should be performed on the basis of local conditions. Moreover, protection should be enhanced to extend the period of forest establishment to facilitate the progress of regional ecosystem recovery.

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