Journal of Environmental Sciences Vol. 15, No. 2, pp. 167—172, 2003

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2003)02-0167-06 **CLC number**: Q149 **Document code**: A

Comparing the soil quality changes of different land uses determined by two quantitative methods

FU Bo-jie, LIU Shi-liang, LU Yi-he, CHEN Li-ding, MA Ke-ming, LIU Guo-hua

(Key Lab of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China. E-mail: bfu@mail.rcees.ac.cn)

Abstract: Soil quality is one of the most important environmental factors in sustaining the global biosphere and developing sustainable agricultural practices. A study was initiated in Wolong Nature Reserve, Sichuan Province, China to elucidate the soil quality changes of natural secondary succession, forest planting and agricultural practices after deforestation in the humid mountainous region. The soil qualities of six land use types (natural forestland, grassland, shrub land, secondary forestland, cultivated land and reforested land) were compared using two quantitative methods: the integrated soil quality index(*QI*) and soil deterioration index(*DI*). The *QI* values of natural forestland, grassland, shrub land, secondary forestland, cultivated land, reforested land were 0.8039, 0.3277, 0.9127, 0.6881, 0.0285 and 0.3183, respectively. The *DI* values were 0%, −14%, 12%, 1%, −26% and −18% respectively. Both indexes suggested that shrub land can restore soil properties. To compare the two methods more directly, a deduced index *QI'* based on *QI* value was developed. The results showed that *DI* and *QI'* had a very high linear correlation coefficient ($r = 0.9775$) despite the values were different. Both methods were efficient in evaluating the soil quality levels and *DI* was a more simple way in soil quality assessment, while *QI* could show more ecological meanings.

Keywords: land use; deforestation; soil quality; quantitative methods; comprehensive evaluation; Wolong

Introduction

During the last 50 years, as a result of increasing demand for firewood, timber, pasture, shelter and food crops, natural land covers, particularly forests, are being degraded or converted to cropland at an alarming rate in southwestern China, particularly in Sichuan Province(An, 1997). Land use changes may influence many natural phenomena and ecological processes, including soil nutrients and soil water change (Fu, 1999; 2000). The processes greatly impact the direction and degree of soil quality changes in time and space (Wang, 1998). Soil quality has been defined by many authors in recent years (Pennock, 1997). Soil changes are dynamic over time. Human-induced soil changes and their effects on human lives and ecological environments have received extensive attention(Fu, 2001). But in past studies on land use changes, limited attention has been paid to soil quality and its deterioration following the changes (Jamalam, 1998).

Soil nutrients can be changed by the processes that forest is cleared for agricultural cultivation or allowed to revert to natural vegetation or replanted to perennial vegetation. Assessment of soil quality upon conversion of natural forests for varying purposes is of great importance to detect early changes in soil quality. Little study has focused on the soil nutrients and quality changes in post-deforestation processes of succession in the southwestern China (An, 1997). There is a need for research to be conducted under that humid region conditions to determine the effect of land use changes from natural forest to different land use types.

Due to large number of physical and chemical indicators of soil, many methods were proposed to integrate the factors and quantify the soil quality(Adejuwon, 1988). But few studies had the comparison of different methods. Also single soil property evaluations, such as changes in SOM, N, P and K were usually emphasized, and much less attention was paid to a comprehensive assessment of soil quality changes. The results form different researchers are difficult to compare because of the different benchmark soils they used, and therefore, the rate of soil changes can not be accurately assessed and compared (Wang, 1998).

In this study an integrated soil quality index was advanced and the results were compared with soil deterioration index. The objectives of the present study were to (1) analyze the soil quality change of different land uses due to human disturbance and natural succession; (2) compare the two methods in the evaluation of soil quality change.

1 Materials and methods

Foundation item: National Key Project for Basic Research in China (No. G2000046807)

1.1 Description of study area

Wolong Nature Reserve (102°52′—103°25′E, 30°45′—31°25′N) was established in 1963 with an original protected area of 200 km^2 and enlarged to 2000 km^2 in 1975. The study area was originally covered with original forests and experienced high rates of deforestation and secondary succession. Over the years, people living in the surrounding villages have often encroached upon and cultivated agricultural crops in the clear-felled forestland. These intense human activities have hampered the regeneration of existing residual vegetation on clear-felled lands but there were also artificial forests plantation.

Elevation in the reserve ranges from 1150—6250m above sea level and the research sites were limited to the 1800 to 2500m to avoid the effect of climate and parent material. The soil was classified as humic acrisols. The climate of the study area is interior mountain climate with pronounced wet and cool seasons. The mean annual temperature is 8.5 ± 0.5℃, while the mean annual precipitation is about 890 ± 100 mm. Relative humidity ranges between 75.5% and 84.8%.

1.2 Soil sampling methods and processing

In order to assess effects of land use changes on soil properties in the study area, surface soil samples were collected from sites which had the similar landscape properties. The land use types were catalogued into natural forestland, grassland, shrub land, secondary forestland, cultivated land and reforested land. The reason of this selection is that secondary succession after deforestation in Wolong nature reserve generally followed the sequence of grass, shrub, secondary forest and natural forest.

Soil samples (0—30 cm) were collected from different land uses of the adjacent sites and the sample number for natural forestland, grassland, shrub land, secondary forestland, cultivated land and reforested land was 14, 12, 24, 6, 8 and 15, respectively. The examined soil properties included soil bulk density (BD), soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), total potassium (TK), available nitrogen (AN), available potassium (AK) and available phosphorus (AP). The determinations of them were according to China standard method (Editorial Committee, 1996).

1.3 Calculation of integrated soil quality indices (*QI*)

Due to the successive property of soil quality change, the continuous membership functions ($Q(x_i)$) were used for the evaluation index (Li, 1991). The ascending and descending property of the functions was determined by the positive and negative value of capacity score coefficient of principle component analysis. The values are also in accord with the vegetation effects on their corresponding factors. The ascending function and descending function were listed below:

$$Q(x_i) = (x_{ij} - x_{i\min})/(x_{i\max} - x_{i\min}), \quad (1)$$

$$Q(x_i) = (x_{i\max} - x_{ij})/(x_{i\max} - x_{i\min}), \quad (2)$$

where $Q(x_i)$ is the membership value of each soil quality factor; x_{ij} is the values of soil physical and chemical properties which were selected for the soil quality; $x_{i\max}$ and $x_{i\min}$ are the maximum and minimum value of the i soil property.

The condition or importance to soil quality of each indicator was indicated by a weighting coefficient. In this study, the cumulative percentage of principal soil quality components and values of component capacity score coefficient were calculated by the membership values using SPSS program, and weights of the soil quality factors (W_i) were calculated by component capacity score coefficient (Eq.(3)).

$$W_i = \text{component capacity}_i / \sum_{i=1}^{n} (\text{component capacity}_i), \quad (3)$$

where component capacity$_i$ is component capacity score coefficient of i soil quality factor.

Based on the addition and multiplication principle, the integrated quality index (*QI*) was calculated by following equations (Zhang, 1999):

$$QI = \sum_{i=1}^{n} W_i \times Q(x_i), \quad (4)$$

where W_i is the weight vector of i soil quality factor.

1.4 Calculation of soil deterioration indices (*DI*)

The soil deterioration index (*DI*; Adejuwon, 1988) was computed on the assumption that the status of individual soil property under shrubs, artificial woods, grass, secondary forest and cultivation were once the same as that of adjacent soils under the well-stocked natural forest before conversion. The equation of *DI* was expressed below:

$$DI = \sum_{i=1}^{n}((x_i - x_i')/x_i') \times 100\%/n, \qquad (5)$$

where x_i is the value of soil physical and chemical properties selected for the soil quality; x_i' is the property under natural forest condition. Negative value of the BD difference was used for that higher BD value usually indicated land deterioration tendency(Lowery, 1995).

2 Results and discussion

2.1 Land use changes in Wolong Nature Reserve

Human disturbance in Wolong Nature Reserve caused heterogeneity mainly around the living area below 3000m. It was generally recognized that the land use change started form the areas near villages and extended to mountainous area. After the land reform in 1981, the plantation forest land increased a little. But landscape pattern still changed a lot especially in the areas where farmers live.

Fig. 1 gave the area changed of different land use types in 1987 and 1997 of the whole nature reserve. The results showed that cultivated land accounted a large proportion, about 16.5%—18.4% of total area. Due to the increasing population pressure the cultivated area increased by 9.7% from 1987 to 1997. Since forest cutting was forbidden since the foundation of the reserve, the natural forest land area increased by over 9.0%. But the area of shrub land and secondary forestland in 1997 decreased compared with 1987, by 13.06% and 15.80% respectively. This is mainly because the increased firewood and timber demand of local inhabitants.

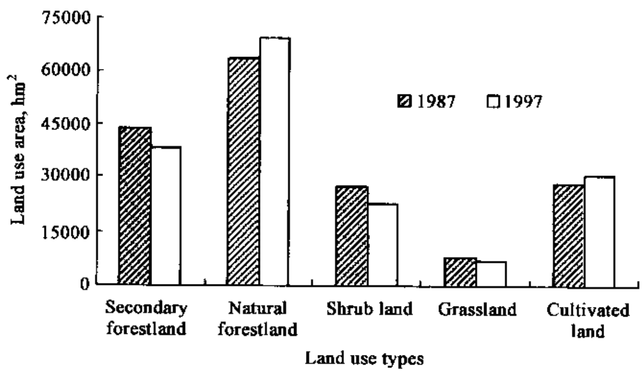

Fig. 1 Area changed of different land use types from 1987 to 1997

2.2 Effects of different land uses on soil properties after deforestation

Table 1 shows the effect of land use type on selected physical and chemical properties for soil quality of adjacent areas in Wolong area. Statistically significant differences were found in SOC, TN, BD, AP and AK among the six land use types. SOC and TN of cultivated land were dramatically lower than of other land uses, but BD was higher. Shrub land had the highest SOC and TN values. Close observation of Table 1 showed that TP, TK, AN, AP, AK showed the lowest or lower values in cultivated land.

Table 1 Effect of land use type on physical and chemical properties selected for soil quality of adjacent areas of similar soils in Wolong Nature Reserve, Sichuan Province

Land-use types	Natural forestland	Secondary forestland	Shrubs land	Reforested land	Cultivated land	Grassland	*F* value
Sample size	14	6	24	15	8	12	
BD, g/cm³	0.72 (0.08)	0.88 (0.18)	0.84 (0.19)	0.99 (0.17)	1.17 (0.15)	1.03 (0.21)	5.71**
SOC, g/kg	65.22 (17.76)	58.18 (8.77)	81.33 (12.12)	44.51 (18.98)	33.12 (7.42)	60.24 (2.70)	5.99**
TN, g/kg	4.45 (1.61)	5.49 (2.04)	6.16 (3.09)	3.82 (2.22)	3.18 (0.71)	4.24 (0.95)	2.58**
TP, g/kg	1.01 (0.41)	1.07 (0.22)	1.04 (0.18)	0.97 (0.22)	1.00 (0.07)	0.98 (0.17)	0.58n.s
TK, g/kg	21.85 (6.17)	21.38 (7.73)	22.02 (5.93)	21.27 (6.0)	17.90 (4.61)	21.61 (4.06)	0.30n.s
AN, mg/kg	1098.62 (309.99)	1073.57 (218.96)	1247.86 (395.13)	998.24 (256.08)	978.56 (75.60)	982.93 (277.99)	1.05n.s
AP, mg/kg	16.00 (4.34)	15.96 (4.65)	14.88 (5.91)	12.87 (5.45)	8.07 (4.03)	9.61 (4.51)	1.97*
AK, mg/kg	362.43 (195.50)	199.77 54.33)	286.50 (164.71)	148.21 (48.85)	123.00 (23.33)	153.46 (46.82)	3.11*

Notes: BD = bulk density, SOC = soil organic carbon, TN = total nitrogen, TP = total phosphorus, TK = total potassium, AN = available nitrogen, AP = available phosphorus, AK = available potassium; numbers in the brackets are standard deviations; * . significant; ** . very significant; n.s. not significant

Soil organic carbon, as a major attribute of soil quality, is responsive to agricultural land use practice including tillage. The result indicated that land use changes influence soil nutrient process and human disturbance could cause soil nutrient loss(Fu, 2000; 2001). The results showed that cultivation decreased soil nutrient levels(Davidson, 1993). Conditions under the shrubs are suitable for the SOC accumulation due to their largest layer coverage, species number, richness and lower light penetration. The vegetations coverage, richness of different ecosystems during secondary succession varied a lot, and so altered the ecosystem biomass and the micro-environmental conditions such as light, water and soil microorganism.

2.3 The *QI* value of different land use types

The calculated integrated soil quality index(*QI*) reflects the relative soil quality degree of different land use types. Using Eq.(1) and Eq.(2), the membership value $Q(x_i)$ of each soil quality factor was calculated(Table 2). Table 3 shows the results of the cumulative percentage of principal soil quality components, values of component capacity score coefficient and weights of the soil quality factors(W_i) using Eq.(3). W_i was calculated by the first component capacity score due to its cumulative percentage had reached 72.55%. The integrated quality index(*QI*) was further derived from Eq.(4).

Table 2 Membership function values of soil quality factor of different land use types

Soil quality factors	Natural forestland	Secondary forestland	Shrubs land	Reforested land	Cultivated land	Grassland
BD	1	0.3184	0.7374	0.6378	0	0.3982
SOC	0.6658	0.5625	1	0.5197	0	0.2362
TN	0.429	0.3573	1	0.7767	0	0.2169
TP	0.4074	0.0614	0.6532	1	0.3	0
TK	0.9592	0.9011	1	0.8459	0	0.8184
AN	0.4458	0.0162	1	0.3528	0	0.0731
AP	1	0.1942	0.8581	0.9954	0	0.6056
AK	1	0.3184	0.7374	0.6378	0	0.3982

Table 3 Cumulative percentage of principal soil quality components, values of component capacity score coefficient and weights of the soil quality factors

Component number	1	2	3	4	5	6	7	8
Percent of variance	72.55	12.55	7.73	5.66	1.51	0	0	0
Cumulative percentage	72.55	85.10	92.83	98.49	100	100	100	100
Component capacity score	0.159	0.157	0.155	0.111	0.136	0.152	0.154	0.145
Weight	0.136	0.134	0.133	0.095	0.116	0.130	0.132	0.124

Fig.2 shows the *QI* values of different land use types. The results clearly showed that the drastic land use changes had resulted in very different soil quality levels. The *QI* values for natural forestland, grassland, shrub land, secondary forestland, cultivated land and reforested land were 0.8039, 0.3277, 0.9127, 0.6881, 0.0285 and 0.3183 respectively. Shrub land had the highest value while cultivated land exhibited the lowest value. The results validated again that cultivation could lower soil quality levels. The reforested land and grassland showed lower *QI* than natural forestland mainly because of the human disturbance and the animals grazing activity. In contrast, *QI* of shrub land and secondary forestland were higher, indicating they can restore soil nutrients. The more complex community of shrub and secondary forest might be a reason for this change. Thus shrub maybe is an optional choice to restore the soil properties as they can decrease soil erosion and improve soil conditions at the ecosystems scale (Wang, 2000). For some area, it is better to

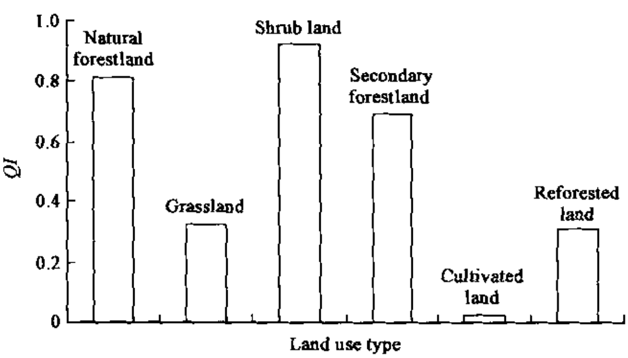

Fig.2 Integrated soil quality index(*QI*) for different land use types in Wolong Nature Reserve

change cultivated land or grassland to shrubs due to the finance or labor shortage.

2.4 The *DI* value of different land use types

Soil deterioration index (*DI*) can be regard as an indication of soil deterioration (improvement) degree. The calculated *DI* reflects the percent changes in soil properties from their values under natural forest (Fig. 3). In our study soils under cultivation had a significantly lower (i.e., negative) *DI* (−26%) than soils under the other land use types. The reforested lands also had a low *DI* (−18%) because some reforested lands were formerly cultivated for agricultural use. *DI* of natural secondary succession after deforestation (grass, shrubs and secondary forest) changed dramatically. *DI* for soils under shrubs and secondary forest were actually positive (12% and 1%), but the grassland had a negative *DI* value (−14%).

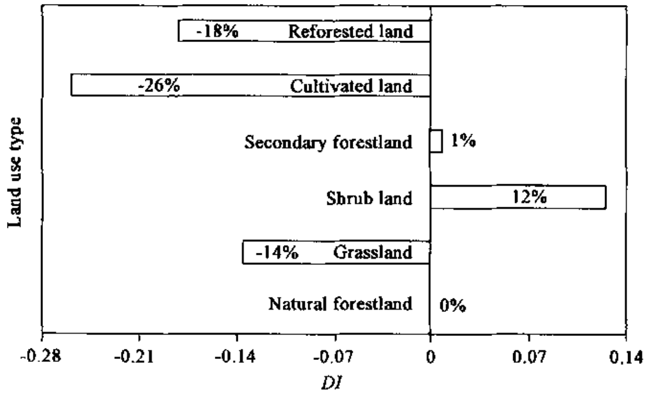

Fig.3 Soil deterioration index (*DI*) for different land use types in Wolong Nature Reserve

Compared with other studies, the *DI* value in cultivated land and the change between different ecosystems were far less (Islam, 2000; Wang, 2000). The cool, humid climate of Wolong maybe is also a factor to the mild soil change of different land uses for the easy soil organic matter accumulation in the native state (Davidson, 1993).

2.5 Comparison of the two quantitative methods

The *QI* and *DI* values of different land use types exhibits the same tendency, but the values have different ecological meanings. To make a clearer and more direct comparison, a deduced index (QI') was cited as Eq.(6).

$$QI' = ((QI_i - QI_{nf})/QI_{nf}) \times 100\%, \quad (6)$$

where the QI_i is the integrated quality index of different land use types; QI_{nf} is the integrated quality index of natural forestland. The treatment method was somewhat similar to *DI*. Fig.4 gave the comparison of QI' and *DI* of six different land use types. The results showed that though the two indices have different values (QI' values range from −96% to 14%, while *DI* values range from −26% to 12%. The positive linear relationship between QI' and *DI* had a high correlation coefficient ($r = 0.9775$).

The comparison results showed that both the quantitative methods were efficient in evaluating the soil quality levels. Soil deterioration index (*DI*) method is a more simple and direct way to determine the changes of soil nutrients. Due to the larger variation range of QI', integrated soil quality index (*QI*) method maybe is a better way to discern the small change of land use change such as continuous succession. Also the calculation process of *QI* contains more ecological meanings.

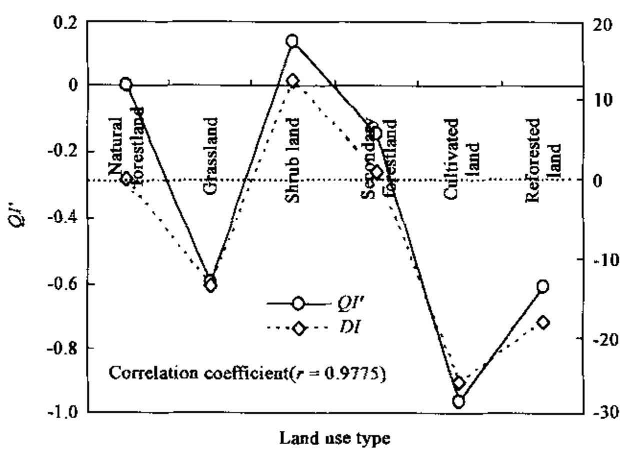

Fig.4 Comparison of QI' and *DI* of six different land use types. There exists a high correlation coefficient ($r = 0.9775$) between QI' and *DI*

3 Conclusions

Subsequent secondary succession after forest cutting and human disturbance caused ecosystem heterogeneity in Wolong Nature Reserve. The cultivated land area increased 9.7% from 1987 to 1997 due to the increasing population pressure. In this study, soil quality of six typical land use types were compared with two different quantitative methods. ANOVA showed that there were significant differences for soil properties among land uses. Soil nutrients in the cultivated land had lower levels than other land uses but the BD had higher values. Both the integrated soil quality index(*QI*) and soil deterioration index(*DI*) showed the same tendency of soil quality levels of different land use types, i.e. shrub land > natural forestland > secondary forestland > grassland > reforested land > cultivated land. This means shrub land maybe is an optional choice to restore the soil properties for the areas where the conditions are suitable for shrubs secondary succession.

A deduced index(*QI'*) calculated from the *QI* value was proposed to make a clearer and more direct comparison of the two quantitative methods. The results exhibited the *QI'* and *DI* had a high positive linear relationship correlation coefficient ($r = 0.9775$), thus both the quantitative methods were efficient in evaluating the soil quality levels.

References:

Adejuwon J O, Ekanade O, 1988. A comparison of soil properties under different land use types in a part of the Nigerian cocoa belt[J]. Catena, 15:319—331.

An S Q, Wang Z F, Zhu X L *et al*., 1997. Effects of soil factors on the secondary succession of forest community[J]. Acta Ecologica Sinica, 17(1):44—50.

Davidson E A, Ackerman I L, 1993. Changes of soil carbon inventories following cultivation of previously untilled soils[J]. Biogeochemistry, 20:161—193.

Editorial Committee, 1996. Soil physical and chemical analysis and description of soil profiles[M]. Beijing: Standards Press of China.

Fu B J, Chen L D, Ma K M *et al*., 2000. The relationships between land use and soil conditions in the hilly area of the loess plateau in northern Shaanxi, China[J]. Catena, 39:69—78.

Fu B J, Guo X D, Chen L D *et al*., 2001. Soil nutrient changes due to land use changes in Northern China: a case study in Zunhua County, Hebei Province[J]. Soil Use and Management, 17:294—296.

Fu B J, Ma K M, Zhou H F *et al*., 1999. The effect of land use structure on the distribution of soil nutrients in the hilly area of the loess plateau, China[J]. Chinese Sciences Bulletin, 44(8):732—736.

Islam K R, Weil R R, 2000. Land use effects on soil quality in a tropical forest ecosystem of Bangladesh[J]. Ecosystems and Environment, 79:9—16.

Jamalam L, Tamaluddin S, Hiroyo N *et al*., 1998. Deterioration of soil fertility by land use changes in South Sumatra, Indonesia: from 1970 to 1990[J]. Hydrol Process, 12:2003—2013.

Li M B, Zhang X W, 1991. Soil fertility progress[M]. Beijing: Chinese Science and Technology Press. 221—234.

Lowery B, Swan J, Schumacher T *et al*., 1995. Physical properties of selected soils by erosion class[J]. J Soil Water Conserv, 50:306—311.

Pennock D J, Van Kessel C, 1997. Clear-cut forest harvest impact on soil quality indicators in the mixed wood forest of Saskatchewan, Canada [J]. Geoderma, 75:13—32.

Wang J, Fu B J, Qiu Y *et al*., 2000. Soil nutrients in relation to land use and landscape position in the semi-arid small catchment on Loess Plateau in China[J]. J Arid Environ, 48:537—550.

Wang X, Gong Z, 1998. Assessment and analysis of soil quality changes after eleven years of reclamation in subtropical China[J]. Geoderma, 81:339—355.

Zhang Q F, Song Y C, You W H, 1999. Relationship between plant community secondary succession and soil fertility in Tiantong, Zhejiang Province[J]. Acta Ecologica Sinica, 2(2):174—179.