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Impact of land cover types on the soil characteristics in karst area of Chongqing

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Abstract: The 26 plots including natural forestland, secondary forestland, shrub-grassland, sloping cropland, artificial forest and abandoned field, were selected to discuss the impact of land cover on the soil characteristics in the three karst districts of Chongqing. The results showed that: (1) After the vegetation turned into secondary vegetation or artificial vegetation, or reclamation, soil physical properties would be degraded. In the surface-layer soil of sloping cropland, the contents of > 2 mm water-stable aggregates decreased obviously with apparent sandification. (2) The contents of soil organic matter and total nitrogen are controlled completely by vegetation type and land use intensity. The increasing trend is rather slow in the early days when over-reclamation is stopped and the land is converted to forest and pasture. (3) Herbaceous species increase and woody plants species decrease with the increase of land use intensity, therefore, the soil seed banks degrade more seriously. (4) The soil degradation index has been set up to describe the relative soil degradation degree under the conditions of different vegetation types. (5) Land cover has a significant effect on karst soil characteristics, land degradation in the karst ecosystem is essentially characterized by the different degradation of soil functions that serve as water banks, nutrient banks and soil seed banks.

Key words: karst ecosystem; vegetation evolution; soil degradation; soil seed bank; soil-land ecology; Chongqing
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1 Introduction

The karst region of Southwest China, with Guizhou Province as the center, extends across Yunnan Province, Guangxi Zhuang Autonomous Region, Sichuan Province, Chongqing, western Hunan Province, Hubei Province, and Guangdong Province, covering a total area of about 6.2×10^5 km^2. This region is one of the vulnerable eco-regions in China (Zhang, 2000), where land degradation problems such as rocky desertification severely hamper its sustainable development, and the eco-environment should be rehabilitated urgently. However, at present, only the correlations between rocky desertification and lithology in the karst areas of Guizhou have been studied (Wang *et al*., 2003), but no holistic study has been conducted on the reciprocity of ecological factors and their influence on the ecological processes of karst ecosystems. And fully understanding of the eco-environmental effects on karst land use/cover changes was also inadequate. Therefore, there has been little information about the characteristics and genesis of land degradation in the karst mountains, which was not favourable to the comprehensive rehabilitation of rocky desertification.

Many vegetation types have been much altered by human land management, including forestry and agriculture (Clemente *et al*., 2004; Michael, 2004; Drew, 1983). Changes of land use patterns pose a threat to natural vegetation community and its soil seed banks (Olatunde Akinola, 1998). Arid karst landscapes degraded by human activities provide a challenge for rehabilitation and an opportunity to test ideas about the stability and resilience of limestone ecosystems (Gillieson *et al*., 1996). Soil and land degradation can be identified and described in terms of physical, chemical and biological changes caused

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by natural and anthropogenic factors (Noble *et al*., 2003). The consequences of land degradation in karst mountainous areas are as follows: the deterioration of hydrological and climatic status, the exposure of bedrocks, the decline of soil quality and the degradation of biological community (Wang *et al*., 2003; 2004), of which the decline of soil quality is the essence of land degradation, including soil loss, deterioration of physical and chemical properties and biological characteristics, as well as spatial heterogeneity of soil distribution. In this work some representative karst mountainous areas of Chongqing are selected to study the changes of soil physical and chemical properties, and those of quality and quantity of soil seed banks during vegetation evolution, and to discuss the mechanism and essence of land degradation in karst ecosystems with an attempt to provide the basis for rehabilitation and reconstruction of optimizing land use cover in the degraded karst ecosystems in this area.

2 The study area and methods

2.1 Generalization of the study area

Chongqing is the fourth city directly under the jurisdiction of Chinese central government and the linkage between developed East and resourceful West in China, which is located in Southwest China and the southeast of Sichuan Basin between $105^{\circ}17'$–$110^{\circ}11'$E and $28^{\circ}10'$–$32^{\circ}13'$N. Most of the Three Gorge area belongs to Chongqing. The exposed carbonate rocks account for 36.18% of the Chongqing's total area of 8.24×10^4 km^2, distributed mostly in the northeast and southeast of Chongqing (Figure 1). A number of karst terrains were selected for this study: (1) Mid-mountains of northeast Chongqing (I): accounting for 34.05% of the total karst area of Chongqing. The exposed carbonate rocks strata belong to Sinian to Jurassic formations, while mid-mountains and gorges were formed predominantly by Triassic carbonate rocks. One is the peak-cluster geomorphologic pattern, formed in the mid-mountainous plateau of the carbonate rocks, and the other is the synclinal low-mid mountains made up of the Badong Formation (T_{2b}) purple clastic rocks interbedded with thin-layered limestone. Generally the carbonate rocks are exposed, and covered by shrub-grass vegetation. (2) Low-mid mountains of southeast Chongqing (II): accounting for 56.66% of the total karst area of Chongqing. The exposed carbonate rock strata belong to Cambrian, Ordovician, Permian and Middle Triassic in age and are distributed in the

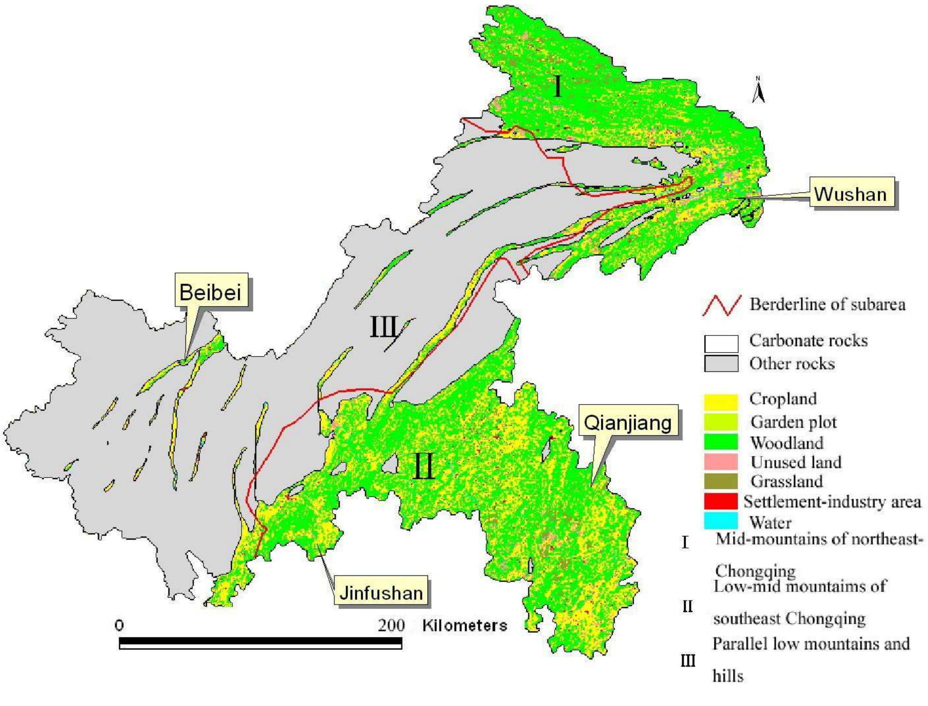

Figure 1 Location of the four representative sites in Chongqing

anticline nucleus, constituting karst mid-mountains. This region is a transitional belt between the Yunnan-Guizhou Plateau and the mountains in western Hubei Province, with some national karst forests seen locally. (3) Parallel low-mountains and hills in the central part of Chongqing (III): accounting for 9.29% of the total karst area of Chongqing, dominated by woodland, shrub-grassland (43.06%), and farmland (42.37%). Anticlines take the form of mountains, while synclines take the form of hills and valleys. Permian and Lower-Middle Triassic carbonate rocks are distributed in the anticline nucleus, forming a geomorphological pattern of "One Mountain — Two Ranges — One Trough" or "One Mountain — Three Ranges — Two Troughs".

2.2 Research method

2.2.1 Site selection and sampling This paper selected the Guanyinxia anticlinal mountain at Beibei District, Qianjiang County and Wushan County representing parallel low-mountain and hilly karst areas, southeast low-mid mountains, northeast mid-mountains, respectively, and the Jinfushan Nature Reserve at Nanchuan representing slightly disturbed karst ecosystem. Because of differences in geology, physiognomy, climate conditions, ecological status, typical land use patterns and economic development of these four areas, they can reflect the overall situation of Chongqing's karst mountains. The ecological evolution were recognized in a sequence as follows: natural forestland ↔ secondary forestland ↔ shrub-grassland ↔ sloping cropland, artificial forestry ↔ abandoned field, and the method of "taking space to replace time" was adopted to choose sampling plots. Plots Nos.1—10 were collected from Beibei, Nos.11—16 from Qianjiang, Nos.17—20 from Jinfushan Nature Reserve, No.21 from Nanchuan (near the Jinfushan mountains), and Nos. 22—26 from Wushan in 2001 (Table 1). The climate conditions of the study area are shown in Table 2, the agrotype is Cab-Udic Cambisols. In each site all the sampling plots were chosen in one integrated karst topographical unit in order to assure consistency in topography. Soil was sampled along soil genetic horizons from the bottom to the top in 26 plots chosen in accordance with topographical positions, land degradation types, land use patterns and variations of vegetation community. Meanwhile, two small plots (40 cm×25 cm) were set up stochastically for soil seed bank sampling (0—5 cm, 5—10 cm, 10—15 cm) in each plot. The biomass and species diversity of ground vegetation were also determined in each sampling plot.

Table 1 The distribution and number of plots studied under different vegetation types

Land type	Total number of plots	Location	No. of plots
Natural forest (meadow)	4	Jinfushan Mountain	17, 18, 19, 20
Secondary forest(1)	6	Beibei, Qianjiang, Wushan	4, 6, 10, 15, 16, 25
Shrub-grassland	5	Beibei, Qianjiang, Wushan	3, 9, 13, 22, 23
Sloping cropland, orchard	8	Beibei, Qianjiang, Wushan, Nanchuan	1, 5, 7, 8, 11, 14, 21, 24
Abandoned field(2)	3	Beibei, Qianjiang, Wushan	2, 12, 26

Notes: (1) The ages of the forestland are 25a, 25a, 15a, 10a, 10a and 8a, respectively; (2) The time durations of abandonment are 1a, 1a and 7a, respectively.

Table 2 The comparison of climate conditions in the four representative sites

Location	Annual mean temperature (°C)	Mean temperature of July (°C)	Mean temperature of January (°C)	Absolute high temperature (°C)	Absolute low temperature (°C)	Annual mean rainfall (mm)	Sunlight (hours)	Relative humidity (%)	Foggy day (days)
Jinfushan	8.2	17.8	-2.4	27.5	-14.4	1434.3	1087.2	90	266.9
Beibei	17	28.7	7.7	43	-3.1	885.3	1293.6	80	89
Qianjiang	8.2-17.1	18.2-27.8	-2.2-5.6	38.6	-5.8	1143-1679			
Wushan	18.4	28.7	7.1	42.1	-6.9	761.5-1356	1542.2		

2.2.2 Analysis method After the original soil samples collected in the field were air-dried, the air-dried soil aggregates and water-stable soil aggregates (including >5 mm, 5—3 mm, 3—2 mm, 2—1 mm, 1—0.5 mm, 0.5—0.25 mm fractions) were determined by dry sift and wet sieving (Yavinov method), soil particle-size distributions by gravimetry, the soil moisture characteristics in the low suction range (<90 kPa) during dewatering processes by quartz sand-kaoline suction flat, and the soil wilting-efficient by plant.

All soil nutrient analyses were carried out on air-dried soil samples sieved through 2 mm screen. Soil total C and N were analyzed by standard acid digestion procedures with external heating (Lu, 2000).

Soil seed bank experiments were conducted by germinating approach. The soil seed bank samples were put into germination frames, with constant soil moisture and illumination, and the germinated species and amounts were recorded, and the time of germination lasted for six months. The species diversity was calculated by Simpson diversity index and Shannon-Weiner index, and on this basis the ecological dominance and richness indices were calculated as follows:

Ecological dominance: $C = \sum_{i=1}^{S} n_i(n_i - 1)/N(N-1)$

where S is the total number of species in plot, n_i is the individual number of species i, and N is the total individual number in plot (Peng, 1987).

Richness index: R_1(Margalef's index) = $(S - 1)/\ln(n)$

R_2 (Menhinick's index) $= S/\sqrt{n}$

where S is the total number of species in plot, and n is the total individual number in plot.

Shannon-Weiner index: $H' = -\sum_{i=1}^{S^*}(p_i \ln p_i)$

Simpson diversity index: $\lambda = \sum_{i=1}^{S} p_i^2$

where S^* is the total number of species in community, S is the number of species in plots, and P_i is the abundance proportion of species i.

3 Results and analysis

3.1 Degradation of soil physical properties

3.1.1 Sandification of surface soil Soil particles are mostly within the range of < 0.05 mm, the contents of clay are generally greater than 20%, belonging to clayey soils and loam soils, controlled mainly by the lithologic character of carbonate rocks in the karst environment. As viewed from the contents of physical clay (< 0.01 mm) and clay particles (< 0.001 mm), the arillization is more intensified in the karst environments at Beibei and Wushan than that at Qianjing and Jinfushan. Some studies have indicated that soils in subtropical zones have higher clay contents in the lower parts of the profile, due to water leaching in response to much rainfall in the subtropical region (Yao *et al.*, 1990), but this phenomenon varied with different land use patterns and vegetation types in the karst environment (Figure 2). The sand contents (1–0.05 mm) of sloping cropland surface-layer and subsurface-layer soils are higher than those of other types of soils. Moreover, the sand contents of surface-layer soil are lesser than those of subsurface-layer due to cultivation activities; the sand contents of soil tend to decrease after the cultivation is abandoned. Compared with sloping cropland, the sand contents of soils in surface and subsurface layers in secondary forests decreased by 40.2% and 80.6%, respectively, and that the illuviation of clay and physical clay is more evident. All these show that the surface-layer soil has been sandified after the reclamation of forestland and grassland.

3.1.2 Changes of soil surface water-stable aggregates Vegetation types and land-use time durations have a great influence on the formation of soil aggregates. They could influence not only the quality and quantity of aggregate composition in surface-layer soil, but also the characteristics of soil aggregates under the surface layer (Figure 3). The water-stable soil aggregates of sloping cropland decrease mostobviously, followed by those of the abandoned field and orchard. For each vegetation type, the surface and subsurface layers' soil water-stable aggregate contents change in a different way, the water-stable aggregate contents of the subsurface-layer soil in sloping cropland and abandoned field tend to increase, and the water-stable aggregate contents of subsurface-layer soil in secondary forestland and shrub-grasslands and orchards show a slight reduction, but the contents of subsurface layer water-stable aggregates (>5 mm, >2 mm, >0.25 mm) in sloping cropland and abandoned field are still lower than in

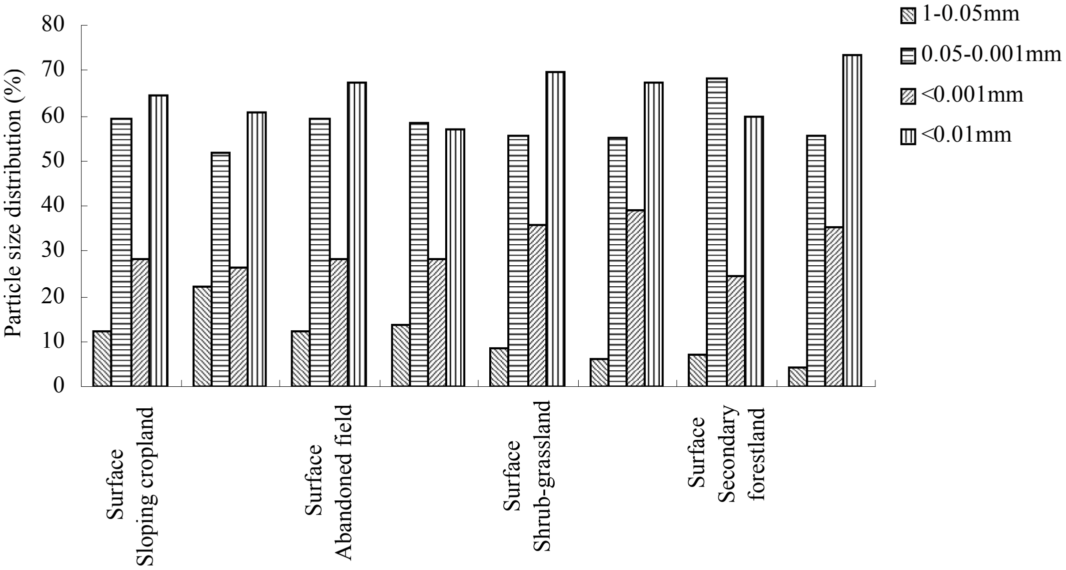

Figure 2 Soil particle-size distribution in karst ecosystems differing in vegetation types

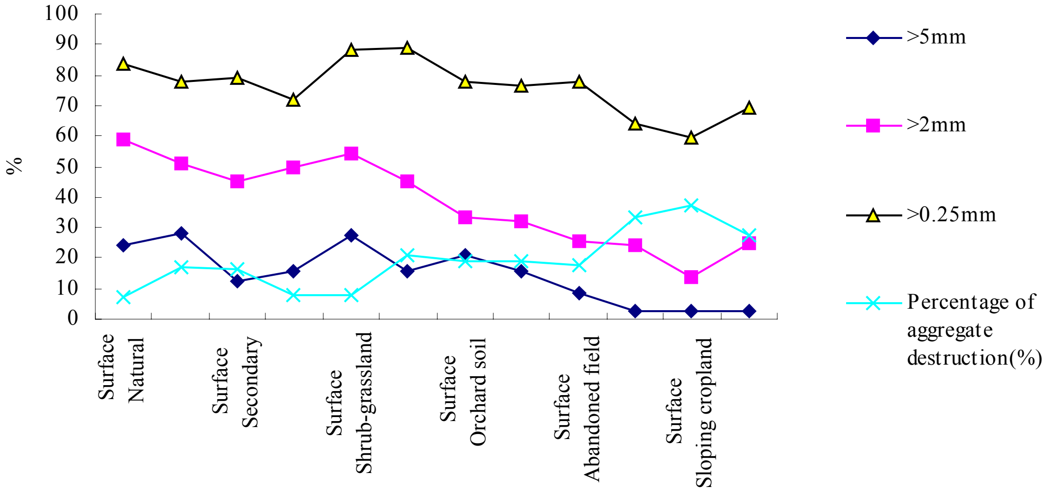

Figure 3 Effects of vegetation types on the water-stable soil aggregates composition

the natural forestland, shrub-grassland, secondary forestland and orchard soil.

The water-stable soil aggregates in woodland and shrub-grassland are made up mostly of >2 mm aggregates, the proportions of >2 mm water-stable soil aggregates in orchard and abandoned field are lower than those of woodland and shrub-grassland; the contents of >2 mm water-stable soil aggregates in sloping cropland, which decrease obviously, are 52.1%, 24.7%, 29.9%, and 22.8% of those in abandoned field, shrub-grassland, secondary forestland and natural forestland, respectively. This result indicates that the cultivation activities have an influence on the larger water-stable soil aggregates. After woodland and shrub-grassland were cultivated, the porosity, water retention capacity, aeration capacity and antierodibility of soil may be lowered as a result of obvious reduction of water-stable aggregates in contents. The water-stable soil aggregates could be rehabilitated to some extent after the sloping cropland cultivation was abandoned, but the restoration of big water-stable aggregates is a rather slow process. For water-stable soil aggregates in the study area, the influence of soil organic matter is greater than that of clay; the contents of SOM are reduced, leading to the reduction of water-stability and quantity of soil aggregates. The soils have abundant clay and inorganic colloids, meanwhile, if these soils have rich SOM and organic colloids, the organic and inorganic colloids cemented together by Ca^{2+}, could form soil organic and inorganic complexes which are hard to decompose. As a result, the water-stability of soil aggregates has been highly improved.

Table 3 The moisture content, bulk density and porosity of soils of different types (%)

Land type	Total porosity	Capillary porosity	Aeration porosity	Non-capillary porosity	Soil bulk density (g/cm^3)	Saturation water content	Field water-holding capacity	Wilting-efficient	Available water content
Sloping cropland	53.77	16.52	16.62	20.64	1.23	45.15	30.36	16.87	13.49
Abandoned field	49.8	16.02	12.46	21.51	1.33	36.85	29.19	17.02	12.25
Shrub-grassland	57.36	29.62	14.07	13.67	1.13	48.2	38.31	12.1	26.21
Orchard soil	51.32	13.08	14.49	23.75	1.29	42.7	28.57	18.4	10.15
Secondary forestland	58.39	21.36	16.29	20.74	1.1	49.03	38.46	18.95	19.60

3.1.3 Changes of soil porosity and soil water contents The surface-layer soils in woodlands and grasslands have a higher total porosity and their pores are distributed more evenly than those of other types of land, dominated by favorable pores such as capillary pores (0.002–0.02 mm) and aeration pores (>0.02 mm), which account for 56% of the total (Table 3). Soils in orchard and abandoned field are lay-textured and compact soils, so their total porosity is low and non-capillary porosity is relatively high. Soil pore capability is worse than that in sloping cropland. The reason why these two kinds of pores are different greatly relative to different vegetation types is the difference in soil aggregate stability and contents of SOM. Only when the contents of SOM reach a certain value can the soil pore structure be ameliorated. If taking soil moisture content under 10 kPa soil suction as the field water-holding capacity (FC), the soil pores with the porosity ranging from saturation water content to field water-holding capacity (namely soil suction from 0 kPa to 10 kPa) are aeration pores, then the influence of vegetation types and land use on soil porosity is focused mostly on the changes of aeration conditions. Table 3 also indicates that there are abundant clay particles in soils from the study area, so the soil wilting-efficient is rather high, however because the soil field water-holding capacity is rather high as well, the effective soil water contents are rather high, too. This phenomenon suggests that the karst ecosystem is, on the whole, a dry environment, but there are many local water predominant microhabitats (Yang *et al.*, 1990).

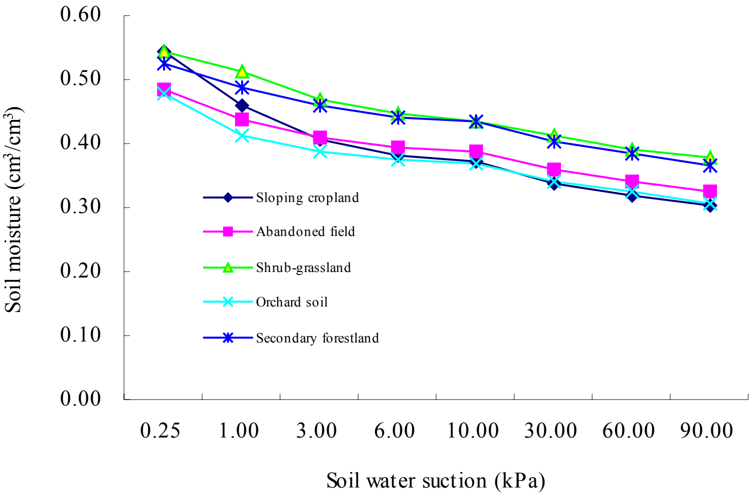

Figure 4 The contents of soil moisture under different suctions

3.1.4 Changes of surface soil water supply characteristics There are differences in soil water holding capacity for different vegetation types and land-use patterns. Soil water-supplying capacity is superior but the water-retention capacity is inferior in sloping croplands, both soil water-retention and water-supplying capacities

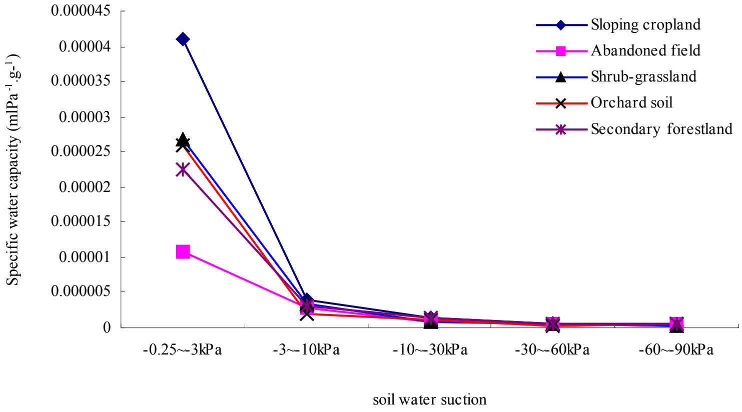

Figure 5 Specific water capacity of soils for different vegetations

are inferior in abandoned fields, both soil water-retention and water-supplying capacities are superior in shrub-grasslands, and soil water-retention capacity is superior but soil water-supplying capacity is inferior in woodlands. This phenomenon is obviously reflected by soil field water-holding capacity and soil available water contents, and can be explained by the fact that the soil moisture contents of sloping croplands and orchards with higher clay (>317 g/kg) under different soil suctions are lower than those of woodlands with lower clay (the clay contents are 283 g/kg and 352 g/kg, respectively) (Figure 4). Why with increasing soil suction, the soil water-retention capacity of intense land use is lower than that of woodlands and grasslands is precisely due to the low contents of SOM and water-stable aggregates of these soils, in addition to their low contents of clay. The water-holding capacity of soils in the study area is correlated mainly with the contents of SOM and >0.25 mm water-stable aggregates, which have played more important roles than clay. In fact, there is a contradiction between soil water-supplying capacity and soil water-retention capacity, and only with higher contents of SOM and good structures could water-retention and water-supplying capacities of soils be well coordinated.

As compared with soil water-retention capacity and soil available water contents, the specific water capacity can better reflect the validity of soil moisture (Chen and Wang, 1979). Specific water capacities tend to decrease with increasing soil suction, but the availability of soil moisture varies with different vegetation types (Figure 5). The specific water capacity of sloping cropland soils is higher than that of woodland soils at -0.25kPa—-10kPa soil suction, but when the soil suction is lower than -10 kPa, it is lower than that of woodland soils, indicating that its longer soil water supplying capacity and soil drought resistance are lower than those of woodland soils. Soil specific water capacities of all plots are close to 10^{-7} (mlPa^{-1}g^{-1}) at -30 kPa—60 kPa soil suction, indicating that soil moistures are generally equal to the available water between BCM (the capillary bond disruption) and PWP (plant wilting point), which is difficult for plants to imbibe. The soil moisture contents under different soil suctions show that 70%—75% of the soil moisture contents at -3 kPa—-10 kPa soil suctions (namely the moisture of the capillary bond disruption, BCM) correspond approximately to the soil moisture contents at –90 kPa. This fact indicates that when soil moisture content is higher still than the theoretic BCM in the soil dehydration processes in the karst ecosystem, plants would be influenced because of soil water deficiency, and this influence may be aggravated by seasonal water deficiency due to spatial-temporal distribution of precipitation, thus resulting in serious drought. Soil clay and SOM are abundant, and soil water-retention capacity is high, too, but soil specific water capacity reflects the quiddity of inferior soil water-supplying capacity in karst environment. Therefore, the key to vegetation restoration and reconstruction is to ameliorate soil structure and moisture ecological effects.

3.2 Changes of Soil organic matter and total nitrogen in surface-layer soil

Soil organic matter (SOM) is one of the key attributes of soil quality, and some researchers suggest that SOM is used as an important indicator of soil quality and soil productivity (Shukla *et al.*, 2004; Doran *et al.*, 1996). The results of analysis of 22 soil physical and chemical indices by the Principal Component Analysis method indicate that the first principal component reflects soil C and N nutrient contents (Li, 2002), thus SOM and total N are discussed emphatically in this paper.

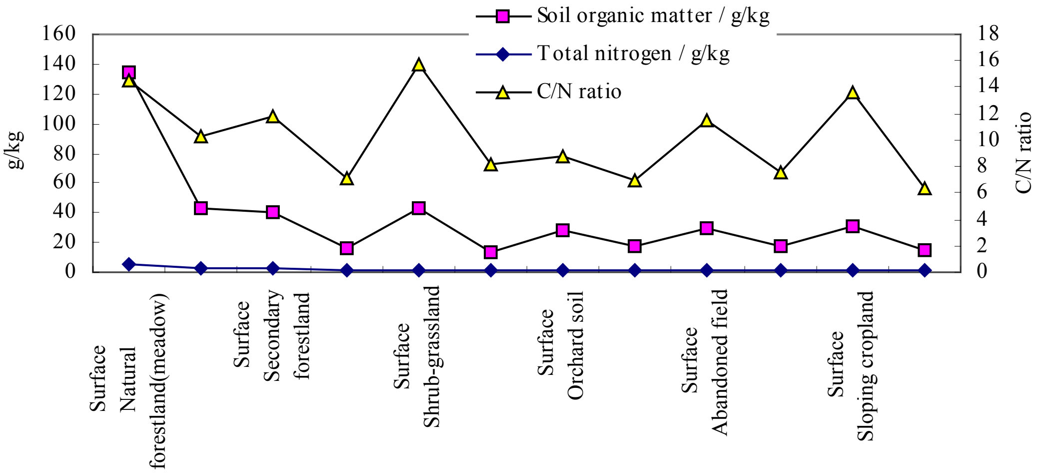

Figure 6 Contents of SOM and total N in soils under different vegetation types

Soil organic matter is more abundant in soils of karst environments than in soils evolved from other parent rocks under the same climate condition, as a result it forms a reservoir of nutrients (Figure 6). SOM contents of the natural forestland system are the highest as a result of supplement of litters, such as those in plot 20, where the Earth's surface litter layer is 6 cm thick, and the contents of its total N, total P, and total K are 15.60 g/kg, 0.150 g/kg, 1.208 g/kg, respectively, but the SOM contents tend to reduce rapidly downwards from the surface layer, showing the characteristics of the yellow soil. The contents of SOM of sloping cropland and orchards are the lowest, after the sloping cropland was converted for forest and grass, the contents of SOM would increase steadily, but the SOM contents of surface layer increased rather slowly in the early days when over-reclamation was stopped and the land was converted to forest land and grassland. The SOM contents of grass slope whose cultivation has been abandoned for 10 years rise by 28.9% and may reach 58.0 g/kg, those of secondary forestland restored for 10 years and 30 years rise by 39.4% and 104.6% respectively, and may reach 63.7 g/kg. Compared with natural vegetation of the Jinfushan Mountains, the contents of SOM of surface and subsurface layers in man-made woodlands, secondary forestlands and shrub-grasslands of the rest karst mountains still have an obvious difference. Variations in SOM contents of surface layer are the result of integrated variation of organic matter in both litter layer and mineral soil (Wu *et al*., 2001), but the accumulation of litter layer is very slow, therefore, it is impossible that the contents of SOM turn back to what they were before vegetation was destroyed.

Soil total N mostly belongs to organic nitrogen, thus its variation in land-use processes may be noticed in a rather long period of time. The contents of total N of surface and subsurface layers soil are significantly high and the contents of total N of litters may reach 15.56 g/kg in natural vegetation of Jinfushan Nature Reserve. It is certainly a result of long-term accumulation. If the land coverage and the contents of SOM are high, and soil erosion is slow in woodlands and grasslands, then, the contents of total N of surface-layer soil would be high correspondingly, and the contents of total N of subsurface-layer soil would also be high. But the contents of total N of subsurface-layer soil in artificial forest developed on the eroded land are relatively low, though the contents of total N of surface-layer soil are obviously higher than those of subsurface-layer soil, and also lower than in soils of secondary forestland and shrub-grassland. Due to cultivation turnover and fertilization, the contents of total N of subsurface-layer soil in sloping cropland and abandoned fields are higher, but the total N contents of surface-layer soil are lower than in orchards and shrub-grasslands. The contents of soil total N may turn back to the value of 1.68 g/kg after cultivation was abandoned for two years.

As a whole, the contents of SOM are high comparatively, but lower C/N ratios indicate that the humification degree of SOM is high, and organic nitrogen is mineralized more readily. Higher C/N ratios in surface-layer soils in natural forestlands and shrub-grass slopes indicate the accumulation speed of carbon is much higher than that of nitrogen, and more carbon is enriched in this soil layer. The declining trend of C/N ratio with vegetation degradation reflects that soil organic carbon decreases more rapidly than nitrogen in the processes of land degradation. Some rules have been found that C/N ratios tend to decrease with the reduction of water-stable aggregates in amounts.

It should be pointed out that Ca-rich litters and soil environments make the contents of SOM in karst ecosystem become higher than those of soils developed at the same latitude. But the damage and reclamation of forest and grasslands make microhabitat types reduce, impoverish and become dry, and the bright habitats expand in area, the fertile, wet and shady habitats decrease, air and the Earth's surface temperatures rise, humidity fall and the aridity of habitats increase sharply. Therefore, the habitat degradation would accelerate the mineralization of active humus of simple structure. The light-fraction organic carbon and particulate-fraction organic carbon, as parts of SOM, relatively easy to decompose, would be exhausted in between 30 years and 40 years, and then there remains only humus combined with Ca^{2+} in cultivated soils (left behind by forest yellow soils), though SOM contents are still higher than those of the ordinary montane forest yellow soils developed at the same altitude (Ren, 1999), but this part of SOM mainly maintains soil structure (Piao *et al*., 2001). The alteration from forest ecosystem to agricultural ecosystem has not only led to a drastic decrease in SOM contents, but also reduced the contents, composition and biological validity of active components such as carbohydrates, bringing about a huge obstacle to the sustainable development of agriculture and environment (Guo *et al*., 2002).

3.3 Degradation of quality and quantity of soil seed banks

Most seeds of soil seed banks are herbage species in the study area, among which the herbaceous species account for the total bourgeon species in Beibei, Jinfushan, Qianjiang and Wushan by 93.1%, 86.2%, 90.7% and 79.2%, respectively. The compositions of soil seed banks of all plots suggest that the species of soil seed banks tend to reduce frequently in cultured lands, woody plant species seeds decrease in amounts, and herbaceous species increase with the increase of land use intensity. The above results illuminate that the variation of quantity and composition of soil seed banks is closely related to fertilization and cultivation. After limestone grass slope is reclaimed into sloping cropland, the former smaller soil seed banks of limestone grass slope would soon be destroyed, causing degradation of both quality and quantity of soil seed banks. In the process of evolution from abandoned field, shrub-grassland to secondary forestland, the quantity of seeds will decrease gradually, the ecological dominance will be reduced and the richness index and diversity index will increase in soil seed banks (Table 4). On the lands frequently disturbed by human activities, although the quantity of seeds in soil seed banks is relatively high, the species diversity index is low, and local suitable and pioneer species are rare. From the point of view of soil seed banks, the evolution from abandoned field, shrub-grassland to secondary forestland will take a longer period of time if natural hillsides closed to facilitate afforestation is adopted. In the herbaceous plant geographical compositions of soil seed banks in shrub-grasslands, the genera of cosmopolitan has a big percentage, indicating that the development of herbaceous layer would be affected greatly by human activities. In addition, there are many calcifuge plants and indifferent plants in the herbaceous layer, too. These plants reflect to some extent that plant floristic elements and ecological types are miscellaneous under the disturbance of human activities.

Table 4 Indices of community structure of soil seed banks

Land type	Number of species	Ecological dominance	Richness index		Diversity index	
			R_1	R_2	Shannon-Weiner	Simpson
Abandoned field	16.0±10.0	0.276±0.132	2.810±1.032	0.195±0.309	1.770±0.634	0.278±0.165
Shrub-grassland	13.6±4.4	0.189±0.036	2.321±0.473	0.985±0.319	2.050±0.408	0.194±0.038
Secondary forestland	20.3±6.1	0.243±0.197	3.604±1.448	1.072±0.491	2.092±0.645	0.248±0.204

The succession phases and restoration potentiality of vegetations are considered by comparing the similarity degree of composition between soil seed banks and vegetations, and the number of tree species in soil seed banks. Most plants of soil seed banks and vegetations are herbaceous species with great similarities in shrub-grasslands which have not been cultivated for 1 year, 3 years or longer indicate that vegetations are still at the early stage of succession and degraded seriously. The soil seed banks of artificial forestry (10a), sparse cypress woods (15a) and secondary forestlands (25a) have evergreen climax species (*Symplocos laurina*), trees (*Rosaceae*) and shrubs (*Vitex negundo*), indicating vegetation communities are slightly affected by human activities and are likely to restore naturally. The soil seed banks of shrub-grasslands and secondary forestlands in the Qianjiang karst mountains have succession pioneer arbor species, hence having a big comparability with land vegetations. Most components in soil seed banks of shrub-grasslands are herbage species, but the soil seed banks of secondary forestlands (the age is 20a) in the Wushan karst mountains have not only pioneer species (*Cunninghamia lanceolata*), but also evergreen broad-leaved species (*Rhus chinensis*), Calciphile species (*Sapium rotundifolium*) and species of *Rosaceae*. The species diversity and quantity of seeds are higher than those of soil seed banks of shrub-grasslands and abandoned fields obviously. The soil seed banks of evergreen broad-leaved forest plots in the Jinfushan Mountain have 2 species of trees, 2 species of shrub and 5 species of herbage (*Cathaya argyrophylla Chun et Kuang* didn't germinate), but some species do not have viable seeds input to the soil seed banks to contribute to community regeneration. This may be related with the ecological countermeasures for part of tree species in karst forest (Liu, 2000), or may be gnawn due to biggish seeds. The numbers of tree and shrub species of soil seed banks in woods of all succession phases are lower than the species of vegetations, showing that the soil seed banks of karst vegetations are fragile, therefore, it is very important to preserve the existing karst vegetation patches and a few tree species in these patches for improving the progressive succession of karst shrub-grasslands.

3.4 The assessment of soil degradation under different types of vegetation

In order to describe the relative degradation degree of soil under different vegetation types quantificationally, the soil degradation index has been set up, depending on the available studies (Guo *et al.*, 2001; Adejuwon and Ekanade, 1988; Islam and Weil, 2000). Take woodlands as fiducial land use patterns (vegetation types) to calculate the differences between other land use patterns and the fiducial land use patterns. The formula is presented as follows:

$$\mathrm{DI}=\frac{n-1}{n}\times\left[\frac{P_1-P_1'}{P_1'}\omega_1+\frac{P_2-P_2'}{P_2'}\omega_2+\cdots+\frac{P_n-P_n'}{P_n'}\omega_n\right]\times\%$$

where DI is the soil degradation index, P_1', P_2', ..., P_n' are the soil indices values of benchmark land cover, P_1, P_2, ..., P_n are the values of soil indices of other land use patterns, n is the number of selected soil properties, and ω_i is the weight of soil properties ($\sum\omega_i = 100\%$). The selected soil properties include soil bulk density, soil organic matter, total N, total P, total K, available N, available P, available K, exchangeable base, pH value, and the contents of >0.25 mm water-stable aggregates (their weights are 9.9%, 11.1%, 10.8%, 6.4%, 9.1%, 10.7%, 8.8%, 9.9%, 10.5%, 5.7% and 7.0%, respectively). If the soil degradation index is positive, it is implied that soil quality is improved; if the soil degradation index is negative, it is implied that soil quality is degraded. In general, higher soil bulk density indicates a trend of land degradation, so the reverse numbers are used in actual calculation of the soil degradation index.

Comparisons of soil degradation indices of surface-layer soil between secondary forest (25a) and other vegetation types in Beibei indicate the relative order of soil quality as follows: grassland which has been abandoned for cultivation for many years (18.7%) >5a orchard (1.4%) > 25a secondary forestland > sloping cropland (-3.1%) > 20a orchard (-4.0%) > sparse woodland (-12.1%) > artificial woodland (-16.9%) > sloping vegetable land (-17.1%) > grassland which has been abandoned for cultivation for one year (-24.1%) > barren grass slope (-27.2%) (numbers in the brackets are soil degradation indices). There is no sight of degradation of grassland which has been abandoned cultivation for many years and orchard (5a), and also there is no sight of obvious degradation of sloping cropland and orchard (20a) compared with secondary forestland soil quality. The soil quality of sparse woodland and artificial woodland does not reach the status of secondary forestland. The soil degradation indices of grassland which has been abandoned for cultivation for one year and barren grass slope are the lowest, so the degradation degree of their soil quality is obvious correspondingly. The change orders described by soil degradation indices and by principal component analyses are generally consistent each another (Li, 2002). These results obtained by the two analysis methods reflect that the soil quality of grass slope which has been abandoned for cultivation for one year and barren grass slope is the lowest, lower than that of artificial woodlands. The soil on the existing karst barren grass slope in Beibei has degraded badly.

The soil quality for all other vegetation types is better than that of *Pinus massoniana* woodlands. Firstly, the soil of *Toona ciliata* woodlands, secondly, the soil of shrub-grass slope, and the soil of abandoned field have been restored obviously relative to secondary forestland in the Qianjiang karst mountains. In the Wushan karst area, the soil quality for all other vegetations is better than that of secondary forest made up mostly of *Pinus massoniana*. In the Jinfushan karst mountains, the soil quality for all vegetations is better than that of *Cathaya argyrophylla Chun et Kuang* forest, and the soil quality of meadow is the best, that of evergreen broad-leaved forest comes next. The soil quality of sloping cropland is relatively high because of agricultural input.

The above results revealed that the relationships between soil quality and vegetation type are complicated in the study area. Land degradation and land restoration succession exist at the same time, and the land quality is dynamic and changeable. After the cultivation is abandoned and the sloping cropland is converted to shrub-grassland, there will be close relations between soil quality and the number of species of soil seed banks. If species diversity in soil seed banks is high and a great number of seeds are conserved, the vegetations could develop rapidly, then the soil quality would be ameliorated, otherwise, the soil quality would be in the inferior state for a long time. It is difficult to restore soil quality by simply abandoning cultivation, it will take a rather long time to ameliorate soil quality by way of afforestation. The comparative measurement of soil quality degradation of barren grass slope and woodlands provides the theoretical basis for ecological restoration of karst barren mountains.

4 Discussion

Under natural conditions, thin layers of soil are developed in the karst ecosystems, with low moisture-supplying capacity, however their soil organic matter and soil fertility are relatively high. The damage and reclamation of forest and grasslands led to the reduction of SOM, active SOM and soil water-stable aggregates, producing clay-textured soil and hardened soil, and making soil permeability drop and soils become wet and dry easily. The conduction capacity of soil becomes poor. All these changes influence the validity of soil moisture and its aeration and permeability. Only the contents of SOM increase to a certain degree, would these physical properties be ameliorated distinctly, this result has been validated by other study (Jiang *et al*., 2005). In the early days of natural forest enclosing, the fertility restoration of degraded soils is reflected by the increase of water-stable aggregates, SOM and total N, though the variations of P, K and pH value are not so obvious. The physical properties dominated by water-stable aggregate and soil fertility (e.g. SOM) are the key factors affecting the soil quality of karst ecosystems.

According to soil fertility and vegetation status in the study areas, the karst ecosystems are divided into four types: well-preserved soil fertility and vegetation, well-preserved soil fertility but degraded vegetation, degraded soil fertility but restored vegetation and degraded soil fertility and vegetation. The development of soil is lagged usually relative to the change of vegetation, and this may explain the differential succession between soil and vegetation. As viewed from soil degradation index, the soil quality of all other woodlands is generally low, as compared with shrub-grasslands and abandoned fields except the woodland of *Toona ciliata* and the evergreen broad-leaved forestland. As can be seen from soil seed banks, the ecological status of all secondary woodlands has been rehabilitated to some extent, though their soil quality may be poor. The barren karst grass slope distributed over a large area has degraded seriously as compared with natural vegetations. The damage and reclamation of forestlands and grasslands would cause not only soil erosion and water loss, but also the degradation of soil seed banks both in quality and quantity. This is the biological problem of karst land or soil degradation, but it has not aroused people's attention.

Therefore, there is an obvious impact of land cover types upon karst soil characteristics, characterizing by the different degradation of soil functions that serve as water banks, nutrient banks and soil seed banks. The characteristics inherited by pedogenic parent materials in karst environments are the internal factors, while the changes of soil seed banks and vegetations resulting from human activities are the external factors. The land use history in karst sites has affected the pattern of regeneration and will continue to affect forest dynamics for many years (Luis and Mitchell, 1998). The karst area is a critical environment for water resources and biodiversity and its conservation and restoration is essential.

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