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COUPLING RELATIONSHIPS BETWEEN PLANT COMMUNITY AND SOIL CHARACTERISTICS IN CANYON KARST REGION IN SOUTH-WEST CHINA

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Abstract

Plant community characteristics in Canyon Karst region in southwest China and analyze the coupling relationships between plant communities and soil properties in different ecosystems have been explored. Eighteen plots (20 × 20 m) in six ecosystems (paddy field, dry land, grassland, shrubbery, artificial forest, and secondary forest) in canyon karst region in south-west China are established. The species composition and diversity characteristics of above mentioned ecosystems were investigated. To find the relationships between vegetation and soil properties, principal component analysis (PCA) and canonical correlation analysis (CCA) were carried out. Forty indices of plant communities and soil properties were chosen. The results showed that with the development of vegetation community succession, species diversity value of the herb layer was larger than that of the shrub. The maximum value of species diversity mainly appeared in the secondary forest. The Canyon Karst Region had high landscape heterogeneity, and different ecosystems had different dominant factors. Species diversity was the dominant factor in karst fragile ecosystems, followed soil microbes and large particle aggregate organic carbon. CCA elucidated a close relationship between species diversity and soil properties (organic carbon, total nitrogen (total P), available nitrogen, Al_2O_3, Fe_2O_3, bacteria, actinomycetes and soil microbial diversity). Thus, in vegetation improvement and management practices, it is necessary to consider the heterogeneity of each factor as well as the relationship between vegetation and soil factors.

Introduction

The karst region in south-west China with the area of 550000 km^2 is considered to be fragile because of its special geological background, small environmental carrying capacity, and low tolerance to artificial interference (Gao *et al*. 2011). In recent years, forests have degenerated into coexisting communities to different degrees as a result of the fast-growing population and intensive soil utilization. The karst region in Guizhou Province has the largest area, the most serious desertification, and the most fragile environment in China (Connor *et al*. 2002). The canyon is one of the typical karst landform structures and accounts for over 30% of the total area of 86 counties in Guizhou Province (Bo *et al*. 2009). Serious soil erosion causes the binary hydrogeological structure (Zeng *et al*. 2007). Soil erosion has become increasingly severe, leading to an expansion of rocky desertification and serious natural disasters, which have restricted sustainable development in this region (Salamanca *et al*. 2006). In the process of ecosystem restoration and reconstruction, it is necessary to explore the vegetation succession law and characteristics of soil development.

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Moreover, vegetation and soil properties were determined by the interaction between plant community and soil environment (Peng *et al*. 2010, Wei *et al*. 2010). Plant community was generally affected by the quality and quantity of soil fertility and soil fertility status was closely related to the diversity of soil microbial structure and function (Song *et al*. 2005, Liu *et al*. 2003).

To clarify the relationship between the plant community and environmental factors, the potential importance of spatial factors, biotic interactions, and other stochastic factors should be considered (Peng *et al*. 2011). The present study was conducted to find the relationship between plant community characteristics and soil properties within six typical ecosystems (paddy field, dry land, grassland, shrubbery, artificial forest, and secondary forest) in Qinglong County of the south-western Guizhou, south-west China.

Materials and Methods

The study area was located in Qinglong County (25°33′N-26°11′N, 105°01′E-105°25′E) of the south-western Guizhou, south-west China. It belongs to the canyon karst with the highest elevation of 2025 m above sea level. This area has a northern subtropical monsoon climate and the average annual temperature ranges 14.0-15.9°C. Mean annual sunshine time is 1453 hrs and the mean annual precipitation is 1500 - 1650 mm. Most of precipitation occurs between June and September. The mean annual frost-free period is 280 days. The average annual evaporation is 1800 mm and the average humidity is 50%. The terrain in the area is composed of high mountains, deep valley, and steep slopes and the soil belongs to weathered limestone soil of Permian strata.

Six typical ecosystem plots (paddy field, dry land, grassland, shrubbery, artificial forest, and secondary forest) in the area were selected. In the paddy field, the main agricultural plant species included rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.). In dry land, the main agricultural plants were corn (*Zea mays* L.) and rapeseed (*Brassica napus* L.). In the artificial grassland, the main plant species included white spines (*Sophora davidii* (Franch.) Skeels), wide leaf finches barnyard grass (*Paspalum wettsteinii* Hack.), perennial ryegrass (*Lolium perenne* L.), and inflorescences (*Dactylis glomerata* L.), white clover (*Trifolium repens* L.), alfalfa (*Medicago sativa* L.), etc. In the artificial grassland, goat is the main domestic animal, including several varieties of Boer goat (*Transgressus* Boer Capra), Local native goat (*Local Niger hircum*), Nanjiang antelope (Nanjiang Yellow) and DuBo sheep (*Dorper oves*). In the shrubbery, the main plant species included Dodonaea (*Dodonaea viscosa* (L.) Jacq.) and tall fescue (*Festuca arundinacea* Shreb.). In the artificial forest, the dominant plant species was catalpa trees (*Catalpa bungei* CA Mey.) and the forest age was between 15 to 20 years. The community structure was simple. The understory vegetation was poorly developed and poorly distributed and the understory coverage was only 6%. The shrub layer was mainly composed of firethorn: *Pyracantha fortuneana* (Maxim.) H. Li (misapplied) and du stem (*Elaeocarpus syluestris* Lour. Poir.). The secondary forest age was between 20 and 40 years. In the tree layer, the dominant species mainly included white oak (*Quercus fabri* Hance), cedrela (*Toona sinensis* (A.Juss.) M.Roem.), and wing pod incense tree (*Cladrastis platycarpa* (Maxim.) Makino). In the shrub layer, the dominant species mainly included the hackberry (*Celtis sinensis* Pers), Broussonetia (*Broussonetia papyrifera* (L.) L'Hér. *ex* Vent.), geranyl tree (*Lindera communis* Hemsl), Yin (*Cinnamomum burmannii* (Nees & T.Nees) Blume), etc.

Experimental design and investigation: In the study area, based on the field investigation, selected six representative ecosystems. Each ecosystem had three plots, which plot included three shrub and three herb layers. The field surveys were conducted in May, 2012. The survey areas of tree, shrub, and herb were 20 m × 20 m, 2 m × 2 m, 1 m×1 m, respectively. For each tree plot, the diameter at the breast height of all the trees and the total number of individual plants were recorded.

In addition, in each shrub plot and herb, species and abundance of each shrub and herb were recorded and all the shrubs and herbs in each plot (including roots) were harvested and weighed. We also collected and weighed the ground litter from each 1 m × 1 m herb plot. Each point was positioned with a GPS system and marked with a bamboo sticker (80 cm high and 8 cm wide). The altitude, vegetation, tillage management, and bare rock ratio were surveyed.

Soil samples were collected in three replicates from each ecosystem from five soil layers at different depths (0 - 10 cm, 10 - 20 cm, 20 - 30 cm, 30 - 50 cm, and 50 - 100 cm). These soil samples were weighed and placed in an aluminum specimen box to measure soil bulk density. A soil drilling sampler was used to collect soil samples from the five layers. The soil samples were placed in sacks, thoroughly mixed, and passed through a 2-mm sieve to remove gravel and roots. Partial soil samples were air-dried in the laboratory to determine the soil nutrients, including pH, soil organic carbon (SOC), total nitrogen (total N), available nitrogen, total phosphorus, available phosphorus, total potassium, available potassium contents were analyzed according to Bao (2000), and MgO, MnO, TiO_2, SiO_2, Al_2O_3, Fe_2O_3, and CaO contents were analyzed according to Liu (1997). Other soil samples were stored in a refrigerator at 4°C to determine soil microbial properties, including fungi, bacteria, actinomyces, soil microbial biomass carbon, soil microbial biomass nitrogen, and soil microbial biomass phosphorus, community metabolism business well color development, Shannon diversity and Shannon evenness, Simpson index and richness of S were analyzed according Wu (2006).

Table 1. Showing the groups of indices used for analysis.

Groups	Indices
Vegetation	Carbon, nitrogen, phosphorus, potassium, richness and Shannon-Wiener index, Simpson index and Pielou index
Soil nutrients	pH value, SOC, aggregate graded SOC (> 5 mm, 2-5 mm, 1-2 mm, 500 mm, 250-500 µm, 53-250 µm), total N, total P, total K, available N, available P and available K
Soil mineral nutrients	MgO, MnO, TiO_2, SiO_2, Al_2O_3, Fe_2O_3, and CaO
Soil microbe	Fungi, bacteria, actinomyces, soil microbial biomass carbon, soil microbial biomass nitrogen, and soil microbial biomass phosphorus, community metabolism business well color development, Shannon diversity and Shannon evenness, Simpson index and richness of S

Forty factors were classified into four groups (Table 1). The relationship between plant community characteristics and soil factors was analyzed using SPSS16.0 software (SPSS INC, Chicago IL, USA). The distribution of the data was tested for normality by check of the abnormal value before analysis. Data were log transformed if the normality failed. (*$p > 0.05$, ** $p < 0.01$).

Results and Discussion

Different community types of different ecosystems in the canyon karst region are summarized in Table 2. The ecosystems in the canyon karst region showed the following vegetation succession direction: secondary forest > artificial forest > shrubbery > grassland. The species richness and Shannon index of the herb layer were decreased in the order: secondary forest > artificial forest > shrubbery > grassland (Table 3). The species richness and Shannon index of the grassland were significantly lower than those of other ecosystems. However, no significant difference was found among other ecosystems. The grassland showed the low Simpson index, while the Simpson index of other ecosystems was relatively high (> 0.8). The Simpson indexes of 4 ecosystems were decreased in the order: artificial forest > secondary forest > shrubbery > grassland. The Pielou evenness indexes of 4 ecosystems were decreased in the order: artificial forest > shrubbery > grassland > secondary forest and no significant difference was found among the 4 ecosystems. In artificial forest, the Shannon index, Simpson index, and Pielou evenness index of the herb layer were greater than those of the shrub layer. In secondary forest, except the Pielou evenness index, other diversity indexes of three layers were decreased in the following order: the herb layer > the tree layer > the shrub layer.

Table 2. Representative community types of different ecosystems in the canyon karst region.

Ecosystems	Family number	Genus number	Species number	Community types
PF	-	-	-	*Oryza sativa+ Triticum aestivum*
DL	-	-	-	*Zea mays + Brassica napus*
GL	7	11	12	*Paspalum wettsteinii+ Trifolium repens*
SH	9	14	15	*Dodonaea viscosa - Imperata cylindrica*
AF	12	17	19	*Catalpa bungei - Broussonetia papyrifera- Microstegium gratun*
SF	19	24	26	*Quercus fabri - Litsea cubeba - Cyperus microiria*

PF = Paddy field, DL = Dry land, GL = Grassland, SH = Shrubbery, AF = Artificial forest, SF = Secondary forest (The same hereinafter).

Principal component analysis (PCA) is applied to convert a multi-index problem into a problem of fewer indexes. In PCA results, the new indexes are not related to each other, but they can comprehensively reflect the information of original multiple indexes. Table 4 provides detailed information related to the main factors of different ecosystems. In each of the six ecosystems, the first four PCs had the Eigen values greater than 1 and accounted for 83.4, 84.7, 83.0, 80.9, 88.7 and 89.4% of the total variations in paddy field, dry land, grassland, shrubbery, artificial forest, and secondary forest, respectively (Table 4). The cumulative contribution rate of the first three principal components was over 80% and could fully reflect all information. The contribution rates of principal components of various ecological systems were very high. Main influencing factors of different ecosystems were different. The first four most important influencing factors of paddy field were total N, available N, MBC, and MBN; the most important influencing factor of dry land was AP; the first three most important influencing factors of grassland were total N, MBC, and MBN; the first four most important influencing factors of shrubbery were CaO%, MBC, MBN, and fungi; the first five most important influencing factors of artificial forest were MBN, MBP, bacteria, fungi, and actinomycetes; the first two most important influencing factors of secondary forest were SOC and available N. According to PCA results of 40 indexes of 18 samples six ecosystems in the canyon karst region (Table 5), the accumulative contribution rate of the first 6 principal components was 90.3%. The first three principal components showed the significant dimension reduction effects of other three principal components were not significant. The difference suggested the high heterogeneity among the ecosystems in the canyon karst region. The factors of the PC1 for the ecosystems in the canyon karst region with the largest loads included plant carbon, nitrogen, phosphorus, Shannon-Wiener, Simpson, Pielou evenness index, and bacteria and corresponding loads were 0.945, 0.940, 0.933, 0.965, 0.951, 0.900, and 0.924, respectively. Plant nutrient content, diversity, and bacteria played an important role in the process of ecosystem succession and evolution. In the factors of the PC2, loads of minerals (MgO) and AWCD were –0.8645 and 0.8645, indicating that mineral nutrient and microorganisms were important in the karst ecosystems and that MgO% played the limiting role. In the factors of the PC3, total K and Fe_2O_3% showed the higher loads and played an important role in the initial succession stage of degraded karst ecosystem as well as the operation process (Yang *et al.* 2007). The factors of PC4, PC5, and PC6 showed the relatively small loads and could be ignored. However, in the study of the interaction relationship among these factors in the karst ecosystem, it is necessary to consider the heterogeneity of each factor as well as the relationship between vegetation and soil factors.

Table 3. Plant diversity indexes of different ecosystems.

Layer	Ecosystems	Pielou evenness index	Shannon-Wiener index	Simpson index	Species richness
Grass layer	GL	0.85Aa	1.21Bb	0.63Bc	4.33Bb
	SH	0.88Aa	2.07Aa	0.85Ab	10.67Aab
	AF	0.93Aa	2.17Aa	0.88Aa	12.00Aa
	SF	0.85Aa	2.27Aa	0.86Ab	14.67Aa
Shrub layer	SH	0.71Ab	0.78Ab	0.44 Ab	3.00Ab
	AF	0.92 Aa	1.25Aa	0.64 Aa	4.50 Aa
	SF	0.96 Aa	1.31 Aa	0.71Aa	4.00 Aa

Table 4. Showing results of the main factors of different ecosystems in the canyon karst region.

Principal	Eco-systems	Principal component factors	Accumulative contribution (%)
Principal component 1	PF	Total N, available N, MBC, MBN	42.63
	DL	Available P	48.30
	GL	Total N, MBC, MBN	46.63
	SH	CaO%, MBC, MBN, Fungi	.40.15
	AF	MBN, MBP, Bacteria, Fungi, Actinomycetes	46.15
	SF	SOC, available N	54.59
Principal component 2	PF	Microbe of AWCD, Shannon diversity (H), Shannon evenness (E), Simpson index(D), Richness (S)	71.98
	DL	MBC, MBN, Actinomycetes	78.77
	GL	Layer plant of Shannon-Wiener index, Simpson index, Pielou evenness	73.18
	SH	Plant evenness (S), Plant Shannon-Wiener index, Simpson index, Pielou evenness	77.92
	AF	PH, AWCD	73.28
	SF	Total P, MBN, Bacteria, AWCD, Shannon diversity (H), Shannon evenness (E), Simpson index (D), Richness (S)	77.24
Principal component 3	PF	-	83.41
	DL	Al_2O_3	84.67
	GL	-	82.95
	SH	Mineral of Al_2O_3%, Fe_2O_3%, TiO_2%	80.86
	AF	CaO, Al_2O_3	88.65
	SF	-	89.35

Table 5. Principal component analysis of the ecological systems in the canyon karst region.

Factors	PC1	PC2	PC3	PC4	PC5	PC6	Commu-nalities	Special variance
Plant C (g/kg)	0.9453	0.2439	–0.0480	0.0666	0.0435	0.0196	0.9622	0.0378
Plant N (%)	0.9396	0.1748	–0.0857	0.1660	0.0810	0.0067	0.9549	0.0451
Plant P (%)	0.9330	0.1792	–0.0567	0.1922	0.1404	0.0522	0.9652	0.0348
Plant K (%)	0.8571	–0.1403	0.2305	0.2858	0.0180	0.0677	0.8940	0.1060
Plant (S)	0.8927	–0.0292	–0.3096	0.1249	0.0753	0.0574	0.9182	0.0818
Plant Shannon	0.9654	–0.1248	–0.0941	0.0034	0.0844	0.0964	0.9728	0.0272
Plant Simpson	0.9514	–0.1564	0.0340	–0.0506	0.1328	0.1248	0.9665	0.0335
SOC (g/kg)	0.4301	0.5482	–0.4997	0.2099	0.1802	–0.0722	0.8170	0.1830
>5 mm	0.6794	0.1237	0.3243	–0.6032	-0.1838	0.0894	0.9876	0.0124
2-5 mm	–0.4062	–0.3561	–0.4411	0.4300	0.2270	–0.4498	0.9251	0.0749
1-2 mm	–0.7404	–0.0694	–0.3804	0.4508	0.0482	0.2238	0.9534	0.0466
500 µm-1 mm	–0.71608	0.1049	–0.3276	0.4578	0.0750	0.3026	0.9389	0.0611
250-500 µm	–0.74802	–0.0702	–0.0096	0.4839	0.2864	0.2716	0.9548	0.0452
53-250 µm	–0.6804	0.1384	0.4401	0.4671	0.1100	0.1234	0.9213	0.0787
total N (g/kg)	0.4883	0.4954	–0.3271	0.3044	–0.2726	–0.101	0.7681	0.2319
total P (g/kg)	–0.1920	0.7133	–0.3900	0.1097	–0.2289	–0.0478	0.7645	0.2355
total K (g/kg)	0.1146	0.4533	0.7358	0.4075	0.0248	0.0183	0.9271	0.0729
available N (mg/kg)	0.5874	0.4778	–0.5161	0.1721	–0.0205	–0.1661	0.8973	0.1027
available P (mg/kg)	–0.7268	0.3722	–0.0899	0.0932	-0.3546	–0.194	0.8469	0.1531
available K (mg/kg)	0.1322	0.5128	0.3951	–0.0036	-0.5990	–0.1043	0.8062	0.1938
SiO_2%	–0.3566	0.7381	0.1464	–0.3916	0.1259	0.1639	0.8894	0.1106
Al_2O_3%	0.1443	0.6883	0.6371	0.0941	0.0819	–0.1323	0.9335	0.0665
Fe_2O_3%	0.0672	0.5093	0.7062	0.1546	0.2886	–0.2947	0.9567	0.0433
CaO%	–0.6994	0.1113	–0.1222	0.3732	-0.4655	–0.0607	0.8761	0.1239
MgO%	0.3035	–0.8645	–0.1025	–0.0083	-0.2292	0.0011	0.9025	0.0975
MnO_2%	–0.4579	0.4163	–0.1581	–0.3065	0.4749	–0.447	0.9272	0.0728
TiO_2%	0.0088	0.6177	0.6764	0.2832	0.1902	–0.0645	0.9597	0.0403
MBC (mg/kg)	0.4874	0.4942	–0.5624	–0.1000	-0.0099	0.1975	0.8472	0.1528
MBN (mg/kg)	0.6683	0.3967	–0.4221	0.1819	-0.3057	–0.0439	0.9106	0.0894
MBP (mg/kg)	0.691	0.3879	0.1696	0.0471	-0.2553	–0.0802	0.7306	0.2694
Bacteria (10^6 cfu/g)	0.9241	0.2806	–0.1150	0.0092	0.0122	0.1301	0.9632	0.0368
Fungi (10^4 cfu /g)	0.8623	0.2961	–0.1887	0.0827	0.0747	–0.1098	0.8912	0.1088
Actinomycetes (10^5 cfu/g)	0.813	0.1881	–0.3267	–0.0408	0.1754	–0.1176	0.8493	0.1507
AWCD	–0.2416	0.8615	0.1194	–0.1033	0.0079	0.3418	0.9423	0.0577
Shannon diversity (H)	0.6734	–0.3787	0.5094	0.3106	-0.1230	–0.0251	0.9686	0.0314
Richness (S)	–0.4797	0.7842	0.0606	–0.1429	0.0389	0.2882	0.9537	0.0463
Eigenvalue	17.1866	7.6408	5.3826	2.8397	1.8191	1.2385		
Accumulative contribution (%)	42.97	62.07	75.52	82.62	87.17	90.27		

Canonical correlation analysis (CCA) was used to determine the correlations between two groups of variables. Forty indexes in the canyon karst region can be divided into four groups. The first group of variables included vegetation factors (X1 - X8). The second group of variables included main nutrients and soil pH (Y1 - Y14). The third and fourth groups of variables were soil mineral nutrients (Z1 - Z7) and soil microbiological characteristics (L1 - L11), respectively. Based on canonical correlation analysis, we investigated the relationship between vegetation and the three groups of variables and established the typical variable correlation (Table 6). Cumulative variance contribution rates of the second, third and fourth groups of variables were, respectively 87.21, 81.06 and 87.37%, thus establishing four groups of typical variables (Table 7).

The first, second and third canonical correlation coefficients between vegetation and soil nutrient factors were 0.888, 0.832 and 0.724. The first three groups of correlation coefficients were larger and the differences were significant ($p < 0.01$).

In the first group of typical variables, vegetation factors with the highest load included plant species richness, Shannon-Wiener index, and Simpson index. In soil nutrient factors, the factors with the highest load included the aggregate grade of SOC (250 - 500 μm), tatol P, and available N, indicating that these factors showed the most significant influences on plant species richness, Shannon-Wiener index, and Simpson index. The plant species richness and Simpson index were negatively correlated with soil total P; the Shannon-Wiener index was positively correlated with aggregate grade of SOC (250 - 500 μm) and available N.

In the second group of typical variables, the plant Simpson index was positively correlated with aggregate grade of SOC (> 5 mm). The third group of typical variables reflected the correlation between plant indexes (plant carbon, plant species richness, and plant Shannon-Wiener index) and the aggregate grade of SOC (250 - 500 μm). Plant species richness was positively correlated with aggregate grade of SOC (250 - 500 μm). The plant carbon and plant Shannon-Wiener index was negatively correlated with aggregate grade of SOC (250 - 500 μm). In typical redundancy analysis (Table 8), 55.7% of variations within variable group could be explained by the first canonical variable (A) of plant factor, which also accounted for 22.4% of variations within the other group (main soil nutrients); 28.5% of variations within variable group could be explained by the canonical variable (A') of main soil nutrient factors, which also accounted for 43.9% of variations within the other group (plant factors); 14.6% of variations within variable group could be explained by the second canonical variable (B), which also accounted for 6.20% of variations within the other group; 8.90% of variations within variable group could be explained by the canonical variable (B'), which also accounted for 13.1% of variations within the other group.

The correlation coefficients of the first two groups of variables between vegetation and soil mineral oxide components were significant ($p < 0.01$). The plant Simpson index and Fe_2O had high loading values, indicating the significant correlation. Similarly, plant carbon storage was strongly correlated with Al_2O_3 and MgO. Moreover, 11.2% of variations within variable group could be explained by the first canonical variable (A) of plant factors, which also accounted for 12.1% of variations within the other group (soil mineral nutrients); 21.3% of variations within variable group could be explained by the canonical variable (A') of main soil nutrient factors, which also accounted for 6.40% of variations within the other group (plant factors); 27.7% of variations within variable group could be explained by the second canonical variable (B), which also accounted for 11.0% of variations within the other group; 21.1% of variations within variable group could be explained by the canonical variable (B'), which also accounted for14.40% of variations within the other group.

The correlation coefficients of the first two groups of variables between vegetation and soil microbe components were significant ($p < 0.01$). Plant P, Simpson index, and bacteria index have high loading values, indicating the significant correlation. The plant Shannon-Wiener index was strongly correlated with microbial Shannon-Wiener index and microbial abundance. Moreover, 59.9% of variations within variable group could be explained by the first canonical variable (A) of plant factor, which also accounted for 21.3% of variations within the other group (soil microbe); 26.4% of variations within variable group could be explained by the canonical variable (A') of main soil nutrient factors, which also accounted for 48.7% of variations within the other group (plant factors); 10.3% of variations within variable group could be explained by the second canonical variable (B), which also accounted for 5.10% of variations within the other group; 9.90% of variations within variable group can be explained by the canonical variable (B'), which also accounted for 15.9% of variations within the other group.

Table 6. Canonical correlation analysis results of different ecosystems in the canyon karst region.

Factor	No. of typical vectors	Canonical correlation coefficients	Eigen values	Chisquare values	Freedom degree	Significant	Accumulative percentage
Main soil nutrients and pH	1	0.8882	11.4360	263.5250	112	0.0001	51.9818
	2	0.8320	3.4176	170.8443	91	0.0001	67.5163
	3	0.7236	2.5960	102.0804	72	0.0059	79.3163
	4	0.6575	1.7375	60.2008	55	0.2504	87.2140
Soil mineral nutrients	1	0.7555	5.4897	124.0028	56	0.0001	36.5978
	2	0.7209	3.5133	70.7110	42	0.0036	60.0196
	3	0.4391	2.2074	24.5186	30	0.7481	74.7359
	4	0.3689	0.9479	11.0258	20	0.9455	81.0549
Soil microbes	1	0.9017	8.3494	220.6839	80	0.0001	46.3854
	2	0.7581	3.8115	118.4164	63	0.0005	67.5606
	3	0.5600	1.9771	66.2687	48	0.1826	78.5442
	4	0.5072	1.5893	43.3162	35	0.5104	87.3734

In the karst region, a land with a total area of 105,000 km^2 has been suffered from rocky desertification with drought or flooding, soil erosion, shortage of available water, and soil nutrients (Baskin 1995). The ecosystems in the karst region are extremely vulnerable under severe soil degradation, water loss, and soil erosion due to intensive land use and human activities. Since the limestone layer in the canyon karst region is covered with thin soils under different water cycling and the species diversity of the ecosystems are sensitive to global change (Burke 2001). With the development of vegetation succession community, species diversity indexes presented in the order: herb layer > shrub layer. The maximum value of species diversity appeared in the secondary forest (Du *et al.* 2013).

Different canyon karst ecosystems achieved the better dimension reduction effect. The cumulative contribution rate of the first three PCs is higher than 80%. PCA results in the paddy field had high loading values for SOC, total N, available N, MBC, and MBN. In paddy field, in addition to topdressing minerals, some management measures, especially rotation or interplanting, could increase species diversity. The dry land had high loading values for SOC (> 5 mm, 2 - 5 mm) and available P. Therefore, in the dry land, regular soil tillage and application of compound fertilizers are recommended in order to improve the microbial population and functional diversity.

Table 7. Canonical variables between vegetation and soil factors (main nutrients, mineral nutrients, and microbes).

Factors	Typical variables
Typical variables between vegetation and main soil nutrients	$V_1=-0.2324X_1-0.1321X_2-0.5675X_3+0.1128X_4-1.4492X_5+4.1406X_6-3.6488X_7+0.5564X_8$
	$V_2=-0.9361X_1-0.4195X_2+1.5380X_3+0.2200X_4-0.2958X_5+2.8594X_6-6.3218X_7+3.2825X_8$
	$V_3=-1.2995X_1+0.4195X_2+0.1754X_3+0.0299X_4+1.3804X_5-1.7593X_6+0.4679X_7+0.8024X_8$
	$V_4=-0.0026X_1+1.5134X_2-0.3170X_3-1.0324X_4+2.3304X_5-11.1686X_6+13.6278X_7-5.3857X_8$
	$N_1=0.3846Y_1+0.0778Y_2+0.0695Y_3-0.0531Y_4+0.0658Y_5+0.4188Y_6-0.6272Y_7-0.1224Y_8+0.1935Y_9+0.4097Y_{10}-0.2006Y_{11}-0.5851Y_{12}+0.2633Y_{13}-0.0890Y_{14}$
	$N_2=0.2138Y_1+0.0623Y_2-1.7198Y_3+0.6340Y_4+0.7874Y_5+0.8880Y_6+0.0740Y_7-0.7464Y_8-0.0616Y_9-0.2463Y_{10}+0.7023Y_{11}+0.2188Y_{12}-0.0092Y_{13}+0.1929Y_{14}$
	$N_3=-0.7484Y_1+0.3253Y_2-0.1434Y_3+0.5053Y_4-0.9317Y_5-0.4344Y_6+1.639Y_7-0.2506Y_8-0.2836Y_9+0.2303Y_{10}+0.0513Y_{11}-0.8476Y_{12}+0.4717Y_{13}+0.3076Y_{14}$
	$N_4=0.2472Y_1-0.8810Y_2-0.4140Y_3-2.6606Y_4+3.5326Y_5+0.7234Y_6-2.0118Y_7+0.5294Y_8-0.0418Y_9+0.1634Y_{10}-0.3155Y_{11}+1.6855Y_{12}+0.3595Y_{13}-0.2004Y_{14}$
Typical variables between vegetation and soil mineral nutrients	$V_1=-0.8738X_1-0.6428X_2+1.2588X_3+0.7554X_4+0.1417X_5+3.7624X_6-7.869X_7+4.0904X_8$
	$V_2=-1.2283X_1-0.1340X_2+0.9281X_3-0.4533X_4+0.2363X_5-0.1370X_6-0.7875X_7+0.6727X_8$
	$V_3=-0.0559X_1+0.2298X_2-1.6115X_3+0.9146X_4+0.3288X_5+1.0251X_6-3.7966X_7+3.0141X_8$
	$V_4=-0.5323X_1+0.0789X_2+0.3922X_3-0.0817X_4+2.5743X_5-13.6086X_6+15.8824X_7-4.0872X_8$
	$M_1=-0.1191Z_1-1.6016Z_2+1.5325Z_3-0.027Z_4-0.2862Z_5-0.8576Z_{6+}+0.8721Z_7$
	$M_2=-0.1285Z_1-1.3795Z_2+0.6155Z_3+0.3533Z_4-1.3976Z_5-0.3289Z_{6+}\ 0.2658Z_7$
	$M_3=0.2981Z_1-2.8927Z_2+2.8147Z_3+0.4450Z_4-0.4401Z_5-1.2314Z_{6-}\ 0.4904Z_7$
	$M_4=0.8031Z_1-0.582Z_2+1.72Z_3-0.4958Z_4-0.4792Z_5-0.9927Z_6-1.393Z_7$
Typical variables between vegetation and soil microbes	$V_1=-0.2486X_1+0.0596X_2-0.5386X_3+0.0394X_4-0.4322X_5-0.2274X_6+0.5676X_7-0.4578X_8$
	$V_2=0.089X_1-0.0761X_2-1.2411X_3+0.7145X_4-2.4113X_5+7.0862X_6-4.091X_7+0.0446X_8$
	$V_3=-1.3166X_1+0.099X_2+0.7018X_3-0.2042X_4+1.1357X_5+1.8641X_6-6.1849X_7+4.0376X_8$
	$V_4=-0.5234X_1+0.4423X_2-0.4996X_3+0.9994X_4-0.2806X_5+2.7361X_6-3.244X_7+0.6436X_8$
	$A_1=0.2874L_1+0.0474L_2+0.3472L_3-0.876L_4-0.3851L_5-0.1306L_{6+}0.258L_7-0.0609L_8+0.0295L_9-0.0295L_{10}+0.0866L_{11}$
	$A_2=0.2682L_1-0.3377L_2-0.0969L_3-0.3685L_4+0.2897L_5-0.2897L_{6+}0.2208L_7+0.9313L_8+0.1923L_9+0.2152L_{10}-1.2406L_{11}$
	$A_3=-0.172L_1+0.179L_2+0.8191L_3-0.3915L_4+0.4596L_5-0.6456L_{6-}1.9752L_7-1.0011L_8+0.0664L_9+1.656L_{10}+1.3261L_{11}$
	$A_4=-0.7243L_1+0.8135L_2+0.5689L_3+0.1066L_4-0.0222L_5-0.6887L_{6+}0.9613L_7+0.4219L_8-0.4011L_9+0.2433L_{10}-1.7653L_{11}$

X_1, plant carbon content; X_2, plant nitrogen content; X_3, plant phosphorus content; X_4, plant potassium content; X_5, species richness; X_6, Shannon-Wiener index; X_7, Simpson index; X_8, plant evenness; Y_1, pH; Y_2, soil organic carbon; Y_3, soil aggregate with the size >5 mm; Y_4, soil aggregate with the size of 2-5 mm; Y_5, soil aggregate with the size of 1-2 mm; Y_6, soil aggregate with the size of 500 μm-1 mm; Y_7, soil aggregate with the size of 250-500 μm; Y_8, soil aggregate with the size of 53-250 μm; Y_9, total N; Y_{10}, total P; Y_{11}, total K; Y_{12}, available N; Y_{13}, available P; Y_{14}, available K; Z_1, SiO_2; Z_2, Al_2O_3; Z_3, Fe_2O_3; Z_4, CaO; Z_5, MgO; Z_6, MnO_2; Z_7, TiO_2; L_1, microbial biomass carbon; L_2, microbial biomass nitrogen, L_3, microbial biomass phosphorus; L_4, bacteria; L_5, actinomycetes; L_6, fungi; L_7: AWCD; L_8, microbial Shannon-Wiener index; L_9, microbial Shannon evenness; L_{10}, microbial Simpson index; L_{11}, microbial species richness.

The grassland had high loading values for total N, MBC, and MBN. Therefore, it is necessary to sow the seeds of other plants to ensure the diversity and rationality of the community structure. The shrubbery had high loading values for SOC (250 - 500 μm, 53 - 250 μm), CaO%, MBC, MBN, and fungus. In the shrubbery, it is necessary to consider the diversity and increase the three-dimensional structure of shrubbery. The artificial forest had high loading values for SOC (>5 mm), MBN, MBP, bacteria, fungi and actinomycetes. Therefore, it is necessary to increase the main nutrients and mineral nutrients, and plant other tree species to improve the community diversity in the artificial forest. The secondary forest had high loading values for SOC and available N, and showed the more complex ecosystem than artificial forest. In the secondary forest, it is necessary to increase the main nutrients, mineral nutrients, and the complexity of trees for the purpose of avoiding the condition of a single species. PCA results indicated that the six typical ecosystems had high degrees of complexity and heterogeneity.

Table 8. Typical redundancy analysis of different ecosystems in the canyon karst region.

Factors		Variation ratios of observed values explained by typical variables (%)					
		A	B	C	A’	B’	C’
Vegetation and main soil nutrients	Directly	55.69	14.62	28.45	8.91	11.52	8.91
	Relatively	43.94	10.12	22.44	6.17	6.03	6.17
Vegetation and soil mineral nutrients	Directly	11.21	27.73	21.27	21.09	14.16	21.09
	Relatively	6.40	14.41	12.14	10.96	2.73	10.96
Vegetation and soil microbe	Directly	59.85	10.27	26.38	9.92	9.31	9.92
	Relatively	48.65	5.90	21.27	5.12	3.05	5.12

In the karst region, vegetation has the close relationship with soil properties. It is generally believed that plant communities are regulated by the soil fertility. The soil fertility status is closely related to soil microbial properties. Plant roots and litters can improve soil fertility and microbial properties and mineral nutrients generated by the melting corrosion and weathering gradually form the material basis of the soil. In the canyon karst ecosystems, the vegetation community types and the conditions of growth and development are regulated in the circulation of material and energy. However, different degrees of degradation appeared under strong interferences, thus producing the coexistence of a variety of various ecosystems and different succession stages. Plant diversity and soil nutrients are the important factors affecting vegetation growth and development in the canyon karst region. On the whole, plant and microbes are the dominant factors. Soil nutrients mainly contain large particle aggregate organic carbon, followed by other nutrients and mineral nutrients. The above soil features are the same to those in ecosystems in the karst peak-cluster depression (Liu 2009). Along with the succession development in different stages (paddy field, dry land, grassland, shrubbery, artificial forest, and secondary forest), the more reasonable community structure, more complex diversity, the better plant growth and development will be realized.

On the whole, the plant diversity is the foundation of a stable community. The ecosystem in vegetation improvement and management practices had many influencing factors. It is necessary to consider the heterogeneity of each factor as well as the relationship between vegetation and soil factors. However, plant and microbes are the dominant factors.

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