A CORRELATION ANALYSIS OF ROCKY DESERTIFICATION GRADES, PLANT DIVERSITY AND SOIL FACTORS IN CENTRAL HUNAN OF CHINA

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ABSTRACT

Karst rocky desertification (RD) in central Hunan is a part of karst land degradation in southwest China. The change in grade of RD, or succession, has led to ecological degradation and seriously hindered socioeconomic development. RD succession is influenced by soil and vegetation. Taking central Hunan regions as a study area and using SPSS17.0 statistical software, we investigated the correlation between RD grades, plant diversity index and soil factors. Results showed that RD grades showed a significant positive correlation with soil organic matter (OM) and cation exchange capacity (CEC).

The plant diversity index was positively correlated with the soil fertility index and showed a significant positive correlation with OM and available elements. Further analysis on the available elements showed that total plant diversity indices including Shannon-Wiener index H', Pielou index E and Simpson P had significant positive correlations with available magnesium (AMg). Total plant diversity indices E and P had significant positive correlations with available calcium (ACa). These conditions might have closely reflected the particular microhabitat types of RD regions.

The correlation between RD grades, vegetation and soil factors suggested that the relationship of the three was co-evolutionary. To enhance RD control and treatment effectiveness, increasing the content of the ACa and AMg may be more impactful than increasing the content of OM in central Hunan.

Keywords: *Central Hunan; RD grades; plant diversity; soil factors; correlation*

INTRODUCTION

Karst rocky desertification (RD) is a process of karst land degradation involving soil erosion, bedrock exposure, water loss, and vegetation reduction, which leads to the development of a desert-like landscape that causes drastic decreases in soil productivity (Wang et al., 2004). RD is classified into four grades, namely potential rocky desertification (PRD), light rocky desertification (LRD), medium rocky desertification (MRD) and intensive rocky desertification (IRD) based on the soil depth, vegetation coverage, vegetation type, and bedrock exposure (Wang et al., 2004; Xiong et al., 2009).

The changing process of karst land from each grade to another is called RD succession (Xie and Wang, 2006). Some mountainous areas of central Hunan province are included in the largest karst geomorphologic distributing region of southwest China. It is one of three regions of high ecological vulnerability within the world's largest karst-concentrated area (Su et al, 2002). Soil erosion, water loss, vegetation reduction and their impacts on the surrounding human communities are amongst the highest in this region. (Wang, 2003; Huang and Cai, 2007). Immediate RD control and treatment is necessary to improve the ecological environment of the region and inhibit further expansion of RD in central Hunan.

Since 1979, ecological and environmental problems in karst areas have been intensifying and many countries have attached great importance to the research of karst environmental problems (Jiang and Yuan, 2003; Huang, 2007). Karst environmental problems are of particular concern in China, where more scientists are beginning to study the origin and governance models of RD in vegetation, soil, irrigation, industrial structure, population and so on. With regard to vegetation and community types in RD regions, the plant communities were divided into different vegetation types and formation groups (Wu et al, 2011; Ou et al, 2004; Li et al, 2003).

As for community characteristics in the process of vegetation restoration at various stages, vegetation succession and advantage species were put forward. This indicated that the substitution process in different recovery stages of plant communities emerged from a low-level community stage to the advanced stage of community recovery in RD regions (Yu, 2002). Different governance models were put forward according to different stages.

As for soil, the spatial distribution of the soil (Zhou et al, 2010), changes in soil nutrients (Huang et al, 2012; Hu et al, 2014; Xie et al, 2014), changes in soil moisture (Fan et al, 2009), influence of soil moisture on forest planting (Li et al, 2008) and soil quality resilience (Long et al, 2005) in the process of RD were studied. In addition, suggestions were proposed from the construction of water conservancy projects, adjustment of rural industrial structure and anthropogenic factors in RD regions.

In short, scientists have carried out various aspects of research on the treatment of RD and have made significant achievements, but correlations among the RD grades, vegetation and soil are still unclear. This study was carried out to perform correlation analysis of RD grades, vegetation types, and soil factors in RD succession. It will provide scientific guidance for RD control and treatment in central Hunan.

STUDY AREA AND RESEARCH METHODS

Study area

The central region of Hunan is located between the east longitude of 110° 20' and 112° 50' and north latitude of 26° 37' and 28° 33' (Fig. 1). The RD area of central Hunan belongs to the south China fold system of the late and Mesozoic carbonate karst area (Yu, 2003). The area displays a zonal distribution pattern with many traits, such as corrosion resistance and soil insufficiency. The RD area covers 3875.85 km^2 with a PRD area of 3921.45km^2. The region is part of a subtropical warm-moist monsoon climate zone. Vegetation is primarily broad-leaved evergreen or deciduous broad-leaved mixed forest. Average annual temperatures range between 17.2 and 18.7°C, with cumulative temperatures greater than 10°C between 5500°C ~5730°C, and annual precipitation between 1300 mm and 1554 mm.

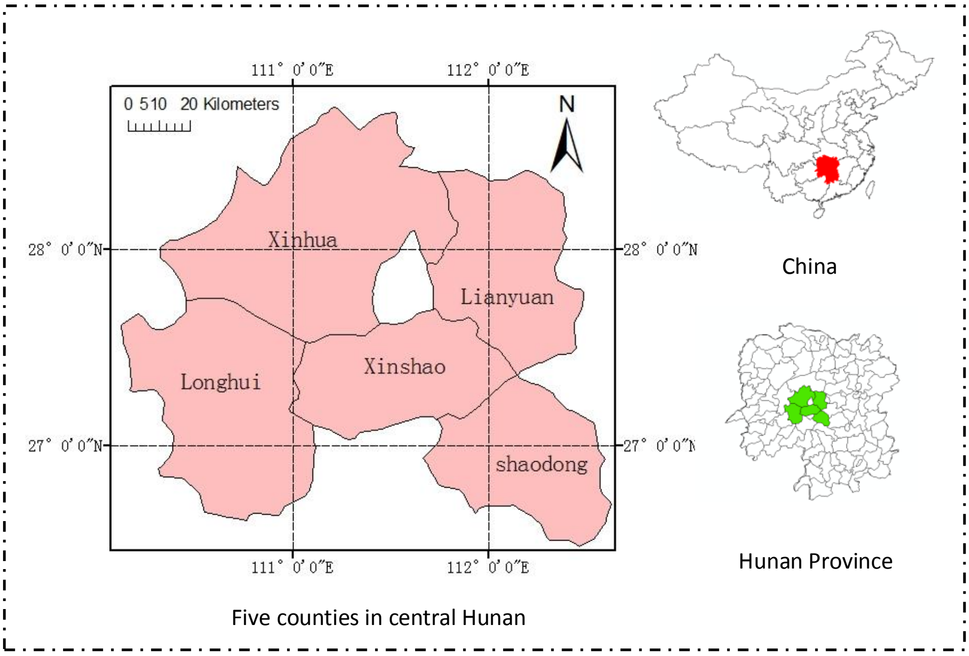

Figure 1. *The location of RD regions in central Hunan*

Research methods

Sample collection

In accordance with the Monitoring Rules of Rocky Desertification in Hunan Province, established by the Hunan Provincial Bureau of Forestry, the samples of PRD、LRD、MRD and SRD were selected (Fig.2) from five counties of the central Hunan province: Lianyuan, Xinhua, Longhui, Shaodong and Xinshao. Four typical plots with different RD grades in every county were made as the sampling sites. Each plot was 400 m^2 in size.

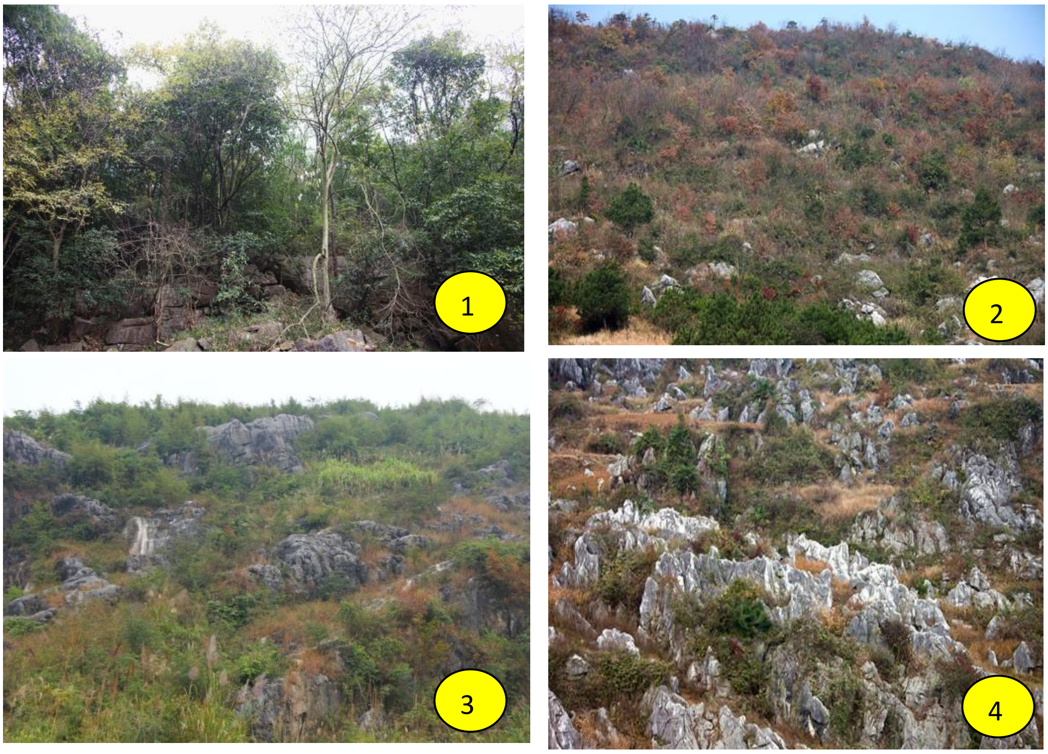

Figure 2. *The landscape of four rocky desertifications in central Hunan Province*

RD evaluation index

The RD evaluation index includes vegetation coverage, bedrock exposure, soil depth and vegetation type. Due to difficulties with quantifying vegetation type, only the data from vegetation coverage, bedrock exposure and soil depth were used for correlation analysis. Vegetation coverage was surveyed on the sampling sites using the methods described by Hu et al., (2007) and White et al. (2000).

Bedrock exposure was estimated using dimension measurements on the sampling sites based on calculating the ratio of bedrock area to whole image (Hu et al., 2007; White et al., 2000) using a Nikon DTM322 total station surveying instrument (Nikon-Trimble Co. Ltd., Japan). Soil depth was directly measured using a ruler after digging up soil slopes at the sampling sites.

Vegetation sample collection and data analysis

Vegetation diversity included the species richness (S), Shannon-Wiener index (H'), Pielou index (E) and Simpson index (P). According to the methods and technical specifications of plant community inventory created by Fang et al (2009) the species, number, diameter at breast height or base diameter, tree height, crown or coverage of trees, shrubs and herbs at the sampling sites were recorded.

The data was used to calculate the species richness (S), Shannon-Wiener index (H'), Pielou index (E) and Simpson index (P). Total S, H', E and P were respectively equal to the total S, H', E and P of trees, shrubs and herbs at the sampling sites.

Soil sample collection and measurement

Eight to 12 soil samples were gathered at depths from 0 ~ 20 cm in each plot. One kilogram of soil was taken at four different points of each plot and used to measure soil chemical indices.

At the same time, 200 g soil samples were similarly collected and used to determinate microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial biomass phosphorus (MBP). Soil pH was measured using a combined glass electrode with 1:2.5 (w:v) ratios of soil to 1mol/L KCl in distilled water. Organic matter (OM) was determined by potassium dichromate method. Total nitrogen (TN) was measured by Kjedahl determination method after digestion (Brookes et al., 1985a). Total phosphorus (TP) and total potassium (TK) contents were measured by sodium hydroxide method (Smith and Bain, 1982).

Available phosphorus (AP), available potassium (AK), available calcium (ACa), available magnesium (AMg), available iron (AFe), available manganese (AMn), available copper (ACu) and available zinc (AZn) were determined using Mehlich 3 extracting method (Sims, 1989). Cation exchange capacity (CEC) was determined by ammonium acetate EDTA method (Zou et al., 2009). The MBC, MBN and MBP were measured by chloroform-fumigation method (Brookes et al., 1985b; Wu et al., 1990).

Correlation analysis

The correlation analysis of the RD index, soil factors and plant diversity index was performed using SPSS17.0 software.

RESULTS AND DISCUSSION

Correlation between RD grade index and soil factor

Vegetation coverage, bedrock exposure, and soil depth had important effects on the soil factors. Results （Table 1）showed that soil depth and vegetation coverage were positively correlated with vegetation coverage, OM, total of TN, TP and TK, available elements, CEC, total of MBN, MBP and MBK and C/N. But bedrock exposure was negatively correlated with OM, total of TN, TP and TK, available elements, CEC, total of MBN, MBP and MBK, and C/N. Soil depth, bedrock exposure and vegetation coverage were uncorrelated with pH and C/N.

The correlation coefficients of soil depth and OM, vegetation coverage and OM, bedrock exposure and total of TN, TP and TK, and vegetation coverage and available elements, were high, they were 0.989, 0.955, - 0.988, and 0.969, and has reached significant level ($p < 0.05$). The correlation coefficients of soil depth and available elements was 0.994, and has reached extremely significant level ($p < 0.01$). This show that the process of RD succession from intensive to light grades has a large influence on the soil fertility factors, it is beneficial for accumulating OM, total of TN, TK and TK and available elements in the soil.

Table 1. *Correlation between RD grade index and soil factors*

	pH	OM	total of TN, TP and TK	Available elements	CEC	Total of MBN, MBP and MBK	C/N	C/P
soil depth	-0.156	0.989*	0.914	0.994**	0.746	0.786	0.727	-0.289
bedrock exposure	-0.112	-0.923	-0.988*	-0.931	-0.653	-0.854	-0.519	0.041
vegetation coverage	-0.032	0.955*	0.948	0.969*	0.652	0.776	0.641	-0.148

Soil depth is an important index for evaluating the RD grades. It has a great influence on soil quality—the thicker the soil depth, the greater the adhesion between soil and rock. This can reduce water and soil loss.

Soil is a carrier of soil fertility factors. The thickening of soil is conducive to the accumulation of OM. OM content is the main factor for determining the soil nutrient storage and supply level (Sun et al, 2011; Wang et al, 2011). This study shows that soil depth has a significant positive correlation with OM, total contents of TN, TP and TK and available elements in the RD area of central Hunan. This is in line with the research results studied by Jinguo Huang et al. in RD areas of north Guangdong province (2012). The RD region of central Hunan belongs to the subtropical monsoon climate zone where there is abundant rainfall. The phenomena resulting from RD are more serious in these regions.

Adhesion of soil and rock is small while rain erosion force is strong, which is not conducive to the accumulation of soil fertility factors. Vegetation coverage is also an important criterion for evaluating the RD grades. The complex vegetation type can reduce surface runoff, decrease soil loss, reduce soil available elements loss, and improve productivity of the soil (Li et al, 2009; Luo et al., 2009).

Correlation between RD grades index and vegetation diversity

Results (Table 2) demonstrated that soil depth and vegetation coverage had a positive correlation with the total S, H', E and P in the sample, while bedrock exposure rate had a negative correlation, although it failed to reach a significant level. It showed that the vegetation diversity index, including the total S, H', E and P in the sample, was a gradually increasing trend with the alleviation of RD grades.

Research on the space structure of plant communities showed that soil depth and vegetation coverage were positively correlated with the S of tree layers and negatively correlated with the S of shrub and herb plant layers. The phenomenon of bedrock exposure was the opposite with soil depth and vegetation coverage. This is because the bedrock exposure in IRD regions of central

Hunan is high, making it unsuitable for shrubs and trees to grow. Herbs, however, are able to use the limited soil to complete the entire life cycle. With the alleviation of the RD grades, soil depth gradually increases and shrubs and small trees also increase, contending for sunlight, soil fertility, moisture, etc. with herbs. This could lead to a gradual decrease in herbaceous plants.

Alleviation of shrubs follows a similar trend to herbs, and also displays a negative correlation. Because the competitiveness of the tree is far stronger than the shrubs or herbs, positive correlation of trees with RD grades is greater than shrubs, and the correlation of herbs with RD grades is very small.

Table 2. *Correlation between RD grades index and vegetation diversity*

	Total of S	Total of H	Total of E	Total of P	Trees of S	Shrubs of S	Herbs of S
soil depth	0.772	0.918	0.946	0.922	0.878	0.765	-0.651
bedrock exposure	-0.615	-0.796	-0.83	-0.793	-0.726	0.568	0.665
vegetation coverage	0.668	0.848	0.89	0.855	0.801	0.672	-0.727

	Trees of H	Shrubs of H	Herbs of H	Trees of E	Shrubs of E	Herbs of E	Trees of P	Shrubs of P	Herbs of P
soil depth	0.878	0.45	-0.244	0.878	0.75	0.687	0.878	0.095	0.098
bedrock exposure	-0.726	-0.66	0.385	-0.726	-0.888	-0.476	-0.726	-0.351	0.105
vegetation coverage	0.801	0.571	-0.38	0.801	0.836	0.578	0.801	0.229	-0.052

Soil is the material basis of plant growth. Different soil depths can affect plant species, which influences the vegetation diversity. However, the different vegetation types have a great influence on the total vegetation coverage. As such, there is a significant relationship between the RD grades and plant diversity. The difference of RD grades had a great influence on the vegetation types.

During the positive succession process of RD, vegetation types experienced five stages: grass stage, grass and shrub stage, shrub stage, shrub and tree stage, and tree stage (Peng et al, 2014). In central Hunan plant diversity was positively correlated with each RD grade throughout the entire succession, but did not reach significant levels. The diversity of trees was the highest, and the diversity of herbs was the lowest. This is because herbs and shrubs in the succession process of RD experienced, at first, an increase and then a decrease phase (Si et al, 2008), with each measuring index peaking at different stages (Peng et al, 2014). RD, then, was not remarkably relevant to total plant diversity.

Correlation between vegetation diversity and soil factors

Soil factors had an important role on plant diversity in the RD area of central Hunan. Table 3 showed that the plant diversity index including the total S, H', E and P had a negative correlation with pH and C/P, and the correlation coefficient is smallest, this show that pH and C/P are not important on plant diversity in RD regions of Hunan. The plant diversity had a positive correlation with other soil factors,and the correlation coefficient was relatively large. The correlations of total of S and CEC, total of H', total of E, total of P and OM, total of H', total of E, total of P and available elements, have reached a significant correlation ($p < 0.05$), the correlation coefficients of them were 0.951, 0.966, 0.979, 0.966, 0.952, 0.975 and 0.957.

This indicated that the biggest influence on the vegetation community was OM, available elements and CEC in the RD area of central Hunan. With RD succession from intensive to light grades, OM, available elements and CEC could be rapidly accumulated. In return, the increase in nutrients could enhance the plant diversity in this region.

Table 3. *Correlation between vegetable diversity and soil factors*

	pH	OM	Total of TN, TP and TK	Available elements	CEC	Total of MBN, MBP and MBK	C/N	C/P
Total of *S*	-0.61	0.858	0.528	0.826	0.951*	0.638	0.869	-0.797
Total of *H'*	-0.48	0.966*	0.713	0.952*	0.899	0.706	0.885	-0.637
Totalof *E*	-0.457	0.979*	0.743	0.975*	0.837	0.675	0.896	-0.582
Total of *P*	-0.502	0.966*	0.704	0.957*	0.869	0.669	0.907	-0.638

Soil is one of the major environmental factors in a plant community. The properties of soil are closely related to plant community structure and vegetable diversity, which has always been a focus of ecology research for years (Tilman D et al, 1996; Harrison S, 1999). Studies on the relationship between species diversity and soil factors are the basis of community ecology and biodiversity conservation and management. Studies have shown that the total S shows significant positive correlation with CEC in different grades of RD in the RD area of Hunan.

Correlation between vegetation diversity and soil available elements

The soil available elements had a significant correlation with vegetation diversity in the RD area of central Hunan, next, the correlations of vegetation diversity and every soil available element, including of AK, AP, ACa, AMg, AFe, AMn, ACu and AZn, were studied. Results (Table 4).showed every correlation coefficient of them were more than 0.5. Total of *H'*, total of *E* and total of *P* were significant positively correlated with AMg, the correlation coefficient were 0.981, 0.988 and 0.980, and have reached significant level ($p < 0.05$). The correlation of total of *E*, total of *P* and ACa have reached significant level ($p < 0.05$), their correlation coefficient were 0.975 and 0.955.

The results showed that AMg and ACa in available elements have an important influence on the vegetation diversity in RD regions of Hunan. The accumulation of available elements, especially the accumulation of AMg and ACa, could accelerate the increase of the vegetation diversity, at the same time, the vegetation diversity could increase the accumulation of available element.

Table 4. *Correlation between vegetation diversity and soil available elements*

	AK	AP	ACa	AMg	AFe	AMn	ACu	AZn
Total of *S*	0.739	0.849	0.821	0.889	0.533	0.696	0.549	0.618
Total of *H'*	0.814	0.840	0.950	0.981*	0.751	0.635	0.766	0.776
Total of *E*	0.791	0.786	0.975*	0.988*	0.812	0.553	0.833	0.793
Total of *P*	0.785	0.804	0.955*	0.980*	0.764	0.583	0.786	0.763

The total of *H'*, *E* and *P* showed a significant positive correlation with available elements content and OM. Further analysis on soil available elements showed the total of *E* and *P* a significant positive correlation with soil ACa and soil AMg. The total of *H'* was significantly and positively correlated with soil AMg. Vegetation diversity was positively correlated with OM content. These results are consistent with the findings of Liu et al. (2010), Tilman (2000), Bai (2000), Li (2000).

Plant diversity showed a significant positive correlation with soil effective elements in the process of RD, especially with soil ACa and AMg. These results are the first to be found, which may be associated with the unique habitat of RD in the central Hunan. Plant community characteristics are highly correlated with the habitat of RD, although consideration should be placed on the specific effects of native plant species. Yu (1998) proposed the term, endemic plants, to differentiate plant species in the RD area. The interaction between soil and vegetation is mutual in RD regions, with the soil influencing plants while also being affected by the plant, so the rational use of native tree species for RD control will play a greater role in RD areas.

CONCLUSIONS

In the present study, we found that RD grades were positively correlated with vegetation diversity, OM, and available elements during RD succession in central Hunan. Vegetation diversity was significantly and positively correlated with available elements, particularly ACa and AMg. This information will be useful for guiding the control and treatment of RD in this region. It may provide guidance for making fertilization measures in the process of RD control. In addition to increasing the soil organic matter, an increase in appropriate soil elements, particularly ACa and AMg, will significantly improve governance effectiveness of the RD regions in central Hunan.

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REFERENCES

1) Bai Y F, Li L H, Wang Q B, et al. 2000. Changes in plant species diversity and productivity along gradients of precipitation and elevation in the Xilin river basin, Inner Mongolia [J]. Acta Phytoecologica Sinica. 24(6): 667-673.
2) Brookes, P. C., Kragt, J. F., Powlson, D. S., et al. 1985a. Chloroform fumigation and the release of soil nitrogen: the effects of fumigation time and temperature, Soil Biol. Biochem.,17, 831–835,
3) Brookes, P. C., Landman, A., Pruden, G.,et al. 1985b. Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil, Soil Biol. Biochem., 17, 837–842,
4) Fang J Y, Wang X P, Shen Z H, et al. 2009. Methods and protocols for plant community inventory[J], Biodiversity Science,6:533-548. (in Chinese)
5) Fan X R, Su W C, Yan G Q, et al. 2009. Research on soil moisture dynamic changes in typical karst regions[J], Research of Soil and Water Conservation, 16(2):156-159.(in Chinese)
6) Harrison S. 1999. Local and regional diversity in a patchy land scape native alien and endemic herbs on serpentine soils [J]. Ecology. 80:70-80.
7) Hu N, Yuan H, Lan J C, et al. 2014.Factors influencing the distribution of inorganic phosphorus fractions in different vegetation restoration areas in karst rocky desertification areas[J], Acta Ecologica Sinica, 34(24):7393-7402. (in Chinese)
8) Hu, Z. Q., He, F. Q., Yin, J. Z.,et al..2007. Estimation of fractional vegetation cover based on digital camera survey data and a remote sensing model, Journal of China University of Mining and Technology, 17: 116–120.
9) Huang J G, Li S, Wei X H, et al. 2012. Change of soil nutrient in process of rocky desertification in karst mountainous area of north Guangdong[J], Journal of Desert Research, 32(1):163-167. (in Chinese)
10) Huang Q H, Cai Y L. 2007.Spatial pattern of karst rock desertification in the middle of Guizhou province, southwestern China[J]. Environ Geol. (52):1325-1330.
11) Huang Q H, Cai Y L, Wang X C.2007.Progress of research on rocky desertification in karst areas of southwestern China[J],Journal of Natural Disasters,116(2):106-111.
12) Jiang Z C, Yuan D X. 2003. The comprehensive control countermeasures of rocky desertification of karst area, southwest China[A]. The international symposium of soil and water conservation[C]. 56-60.
13) Liu L L, Jin Z X, Li J H. 2010.Plant species diversity in sinocalycanthus chinensis community and its correlation with soil factors in dalei mountain of Zhejiang province[J].Bulletion of Botanical Research, 30(1):57-64. (in Chinese)

14) Li S. 2008. Environment characteristics of typical karst rocky desertification and the effect of soil water on afforesting tree species[J], Chinese Academy of Forestry Sciences. (in Chinese)
15) Li S, Ren H D, Yao Xiao-hua, et al. 2009. Study on characteristics of runoff and nutrition loss between different vegetation land in typical karst rock desertification zone[J]. Journal of Soil and Water Conservation, 23(2):1-6. (in Chinese)
16) LI X K, SU Z M, LU S H, et al. 2003. The spatial pattern of natural vegetation in the karst regions of Guangxi and the ecological signality for ecosystem rehabilitation and reconstruction[J], Journal of Mountain Science, 22(2):129-139.
17) Li X R, Zhang J G, Liu L C, et al. 2000. Plant diversity in the process of succession of artificial vegetation types and environment in an arid desert region of China[J]. Acta Phytoecologica Sinica. 24(3):257-261. (in Chinese)
18) Long J, Deng Q Q, Jiang X R, et al. 2005. Effects of different de-farming and reafforestation patterns on changes of soil fertility quality in karst region of southwestern China[J], Chinese Journal Of Applied Ecology, 16(7):1279-1284. (in Chinese)
19) Luo H B, Liu F, Liu Y S, et al. 2009. Variation of forest soil organic carbon in karst rocky desertification area[J], Scientia Silvae Sinicae, 45(9):24-28. (in Chinese)
20) Ou Z L, Su Z M, Li X K. 2004.Flora of karst vegetation in Guangxi[J], 4:302-310. (in Chinese)
21) Peng J Q, Cao F X, Cao J W, et al. 2014. Plant community composition and characteristics for different types of rocky desertification in central Hunan[J].Northern Horticulture. (23):65-70. (in Chinese)
22) Si B, Yao X H, Ren H D, et al. 2008.Species diversity in the process of vegetation succession in karst area in western Guangxi[J]. Journal of Southwest University(Natural Science Edition).30(3):113-118. (in Chinese)
23) Sims, J.. 1989. Comparison of mehlich 1 and mehlich 3 extractants for P, K, Ca, Mg, Mn, Cu and Zn in Atlantic coastal plain soils, Commun. Soil Sci. Plan., 20:1707–1726.
24) Smith, B. F. L., Bain, D. C. 1982. A sodium hydroxide fusion method for the determination of total phosphate in soils, Commun. Soil Sci. Plan., 13: 185–190.
25) Song C Y, Guo K, Liu G H. 2008. Relationships between plant community's species diversity and soil factors on otingdag sandy land[J]. Chinese Journal of Ecology.27(1):8-13. (in Chinese)
26) Su W C. 2002. Controlling model for rocky desertification of karst mountainous region and Its preventing strategy in southwest, China[J], Journal of Soil and Water Conservation,16(2):29-32+79.(in Chinese)

27) Sun Y N, Wang J C, Han Q J, et al. 2011. The alpine vegetation and soil characters and vegetation recovery along the Golmud-ando section of the Qinghai-Tibet railway[J], Journal Of Desert Research, 31(4):894-905. (in Chinese)
28) Tilman D, Wedin D, Konops J M H. 1996. Productivity and sustainability influenced by bidiversity in grass land ecosystems [J]. Nature, 349:718-720.
29) Timan D. 2000. Cause, consequences and ethics of biodiversity[J]. Nature, 405:208-211.
30) Wang F, Xiao H L, Su Y Z, et al. 2011.Changes of soil quality after reclamation in Oasis Saline Meadow in Linze, Gansu, China[J], Journal Of Desert Research, 31(3):106-111. (in Chinese)
31) Wang S J. 2003.The most serious Eco-geologically environmental problem in southwestern China-karst rocky desertification[J], Bulletin of Mineralogy, Petrology and Geochemistry,22(2):120-126. (in Chinese)
32) Wang S.J., Liu Q. M., zhang D.F. 2004. Karst rocky desertification in southwestern China: geomorphology, landuse, impace and rehabilitation[J]. Land Degradation Develop, 15:115-121.
33) White, M. A., Asner, G. P., Nemani, R. R, et al..2000. Measuring fractional cover and leaf area index in arid ecosystems: digital camera, radiation transmittance, and laser altimetry methods, Remote Sens. Environ., 74, 45–57.
34) Wu, J., Joergensen, R. G., Pommerening, B., et al.. 1990. Measurement of soil microbial biomass C by fumigation-extraction-an automated procedure, Soil Biol. Biochem., 22:1167–1169.
35) Wu S X, Tian J, Yu X L, et al. 2011.A preliminary study of the natural forest vegetation in the Limestone regions of southern Hunan[J], Journal of Central South University of Forestry & Technology, 31(6):55-64. (in Chinese)
36) Xie L.W., Zhong J., Cao F.X., et al. 2014. Evaluation of soil fertility in the succession of karst rocky desertification using principal component analysis[J]. Solid Earth Discuss. (6):3333-3359.
37) Xiong Y.J., Qiu G. Y., Mo D. K., et al. 2009. Rocky desertification and its causes in karst areas: a case study in Yongshun County, Hunan Province, China[J]. Environ Geol,57:1481-1488.
38) Yu L F. 2002. Southern degraded karst forest natural restoration ecology process and evaluation[A]. China association for science and technology, science and education ahead of west development and the sustainable development-2000 academic convention corpus of China association for science and technology[C]. China Association for Science and Technology (CAST). 2:626-627.
39) Yu S. 2003. Rocky desertification distribution present situation and the characteristics of China[J].Central South forest Inventory and Planning, 22(2): 53-55. (in Chinese)

40) Yu X L, Xiao Y T. 1999. Primary study of limestone endemic plants in Hunan provence [J]. Journal of Central South Forestry University. 1999,19(2):34-38. (in Chinese)
41) Zhou Y C, Wang S J, Lu H M. 2010. Spatial distribution of soils during the process of karst rocky desertification[J], Earth and Environment, 38(1):1-7. (in Chinese)
42) Zou Z, Qiu R, Zhang W, et al..2009. The study of operating variables in soil washing with EDTA, Environ. Pollut., 157:229–236,