Soil Ecosystem Degradation of Karst Regions in Southwestern China

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Abstract Deeply influenced by karst geological environment, the structure of the soil ecosystem in the southwest karst area of China is characterized by strong vertical variation and space variation, structural feature of nonrenewable soil, and functional feature of poor circulation of nutrient elements and limited vegetation growth. On the basis of analyzing vulnerability in structure and function of soil ecosystem in China's southwestern karst regions, we discussed the degradation process and mechanism of soil structure, nutrient, water and microorganism in the course of soil erosion from the perspective of material and energy cycle. Finally, we put forward some recommendations for recovery of degraded soil, transformation and rational utilization of soil.

Key words Soil ecosystem, Unbalance of material cycle, Karst regions in southwestern China

The soil ecosystem is called Pedosphere. As a subsystem of land ecosystem, the soil ecosystem is an open system and energy converter consisting of soil, organism and environmental factors[1]. It is the central link in the course of energy conversion and material cycle of land ecosystem, so it is the fundamental reliance of life support system in ecological system. Karst environment is in the status of strong and rapid variation of carbon material and energy cycle. It is a kind of vulnerable ecological environment with low environmental capacity, small biomass, colony being substituted, highly sensitive to variation of ecological environment system, high ability of space movement, low stability, weak disaster-enduring capacity, and not highly flexible disaster-enduring threshold[2]. As support system of this fragile ecosystem, the soil ecosystem is more vulnerable in system structure and nutrient cycle. To a great extent, the soil ecosystem is determined by normal functions of external forces, such as flowing water, karst, and gravity, and influenced by human activities. The soil ecosystem deterioration in southwestern karst regions is mainly characterized by soil erosion.

The research of soil degradation process and mechanism is one of the hot and difficult points of research of soil ecosystem degradation. Relevant researches[3] indicate that it is an important approach to understand dynamic process and driving force of land ecosystem, and understand damage process and mechanism of degraded soil from change of land utilization, reveal land degradation process, its driving force and degradation mechanism. Chinese scholars have also taken a good many researches[4–13] in the relationship between changes of land utilization and soil degradation in karst regions, and have made new progress. However, among these researches, few touch on dynamic balance of material and energy in the course of soil degradation. In this situation, from the perspective of systematic science and in combination with soil ecosystem structure and nutrient element cycle characteristics, we discussed the dynamic change of material and energy in the course of soil degradation, in the hope of revealing degradation process and mechanism of soil ecosystem in karst environment.

1 Structural features of soil ecosystem in southwestern karst regions

1.1 Vertical variation of soil In general, soil layer in karst regions is thin (10 – 20 cm) and its distribution is scarce. Vertical variation of soil is mainly characterized by the existence of interface between soil and mother rock and between upper and lower layers of soil mass. From the profiling of soil in karst regions, it lacks parental weathered layer between soil mass layer B and mother rock. As a result, soil mass is directly covered onto bedrock, showing interfaces with different hardness. The existence of such interface leads to low affinity and poor adhesion force between rock and soil. After rain penetration, it is easy to lead to underground runoff, the whole soil mass will go downwards, so it is extremely easy to cause soil erosion. Besides, the strong eluviation in southwestern karst regions causes adhesive particles (<0.001 mm) with high content of carbonate weathering substances to fall vertically, forming an interface with different physical properties (loose in upper and adhesive in lower). Interflow of soil, subsurface erosion, creeping and sliding are main erosion ways of slope soil erosion[14]. The existence of interface between soil and rock and between upper and lower soil layers, and discontinuous soil space, greatly reduce internal stability of soil ecosystem in

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karst regions.

1.2 Space variation Southwestern karst regions are not endowed with geological conditions of forming large plain. Soil generated from carbonate weathering is scarcely distributed in small low-lying land, basin and mountain peaks[15]. Regolith in karst regions is often blocked by some abrupt rocks. Such discontinuity leads to limited soil layer thickness and water content, single organism content and microorganism colony. In addition, soil ecosystem has difficulty in enduring pressure of change of external environment. In this situation, in the action of rainfall, artificial disturbance or other external forces, these small soil blocks will be eroded.

1.3 Nonrenewable feature of soil Carbonate minerals mainly consist of calcite, dolomite, clay minerals and quartz, and major chemical compositions are $CaCO_3$ and $MgCO_3$. There are certain differences in total amount of carbonate component and proportion of Ca and Mg in rocks formed in different ages, However, total amount of insoluble matter in rocks is low (generally below 10% or even lower than 1%). Calculated according to analytical data of 132 points sampled in Guizhou, weathering and erosion of limestone is 23.7 to 110.7 mm/ka. If calculated as per the average erosion rate of 61.68 mm/ka and average acid insoluble content lower than 3.9%, 1 000 years may only erode 2.47 mm, in other words, it takes over 4 000 years to form 1 cm thick eroded soil layer, some slower ones even need 8 500 years[16], which are 10 to 80 times slower than non karst regions. Such soil-forming characteristic of carbonate determinates the nonrenewable or vulnerable feature of soil in karst environment, which is also the fundamental difference between karst regions and non-karst regions.

2 Nutrient feature of soil ecosystem in southwestern karst regions

Morphology, migration and biological effectiveness of nutrient elements in soil of karst regions are, to a great extent, restricted by calcium and magnesium rich karst geochemistry. Since the soil forming and curing are realized in carbon matter cycle and Ca-rich environment, it will not only lead to lack of nutrient elements, such as K, I, B, and F stored in the soil, but also reduce effectiveness of Mn, Fe, P, and Zn in the soil. In Ca-rich environment, total phosphorus (TP) content in the soil is relatively high, but the effectiveness is rather low, because phosphorus is easy to be converted into stable calcium phosphate compounds (such as octacalcium phosphate and apatite, *etc*) and be precipitated. As a consequence, the migration rate of phosphorus is low, and it is not easy to slide downward. Potassium content in karst soil is relatively low. In addition to absorption by organism, fixing by clay minerals, as well as loss by dissolution, the effective potassium content is rather low in limestone soil. As to trace elements, the effectiveness of Fe and Mn is much lower than that in other types of soil. Besides, their activity will be impaired by rich calcium carbonate in plant body. As a result, it may lead to lack of Fe and Mn[17]. In the action of karst dynamic force, the soil pH is in the range of 6 to 8, so Zn is easy to form zinc hydroxide and precipitate, and easy to decompose into zinc oxide, then form poorly soluble compounds, such as zinc carbonate, zinc silicate, *etc*[18].

3 Degradation process of soil in southwestern karst regions

The ability of ecosystem to bear external disturbance has certain tolerable range, within which ecosystem may deviate from the initial status. However, once the external disturbance is removed, the status of ecosystem will be gradually recovered. Otherwise, if the external disturbance exceeds the tolerable limit (threshold), the ecosystem will be seriously damaged and it is difficult to recover. As a special ecosystem, the soil in karst regions also follows non-linear feature in responding to external pressure. However, influenced by internal structure and functional features, its threshold of being disturbed is small, and it is extremely possible to change from one state to another stable state with strong comparison.

3.1 Structural degradation of soil When the soil ecosystem remains stable state, its structure takes on an orderly state. In space pattern, it will take on regular replacement and continuity in time sequence. Influenced by karst geological environment, the soil ecosystem in southwestern karst regions is characterized by vertical soil variation, strong space variation and nonrenewable feature. The soil ecosystem there is vulnerable, and within the system, it is extremely unstable. In the action of natural exogenic forces, such as flowing water, karst, and gravity, rich rainfall, barren soil, and carbonate rock in southwestern karst regions interact mutually in time and space. In case of rainfall, especially storms, exposed or semi-exposed soil layers will be splashed by rain or brushed by flowing water, then the soil structure and appearance will be damaged; thus, it indicates that soil erosion is the major factor leading to degradation of soil in southwestern karst regions[19]. In the course of soil erosion, some soil matters run off along the slope and get accumulated at the slope foot or downstream areas, while some soil particles, karst matters and weathering crust move vertically or obliquely, flow into karst crevice, and erode soil in underground system through sinkholes. With continuation of soil erosion, soil matters run off constantly, soil particles remain negative growth, and soil ecosystem structure is gradually degraded (as shown in Fig.1).

Degradation process of soil structure mainly includes soil lamination, cohesion, ossification, and desertification. The erosion threshold of soil in karst regions (*i.e.* the maximum permissible loss of soil) is low. When the soil loss is greater than this threshold, the soil layer will become thinner, and soil will lose its original harmonious soil mass structure. Soil lamination process and constant reduction of soil quantity lead to changes of physical and chemical and biological properties of topsoil, and directly cause entire degradation of soil. Fine particles and adhesive particles in soil are main objects of water erosion. In the event of soil erosion, grains of sand increase in top soil, manifested as ossification; with intensification of degradation, bottom layer and parent material layer gradually get

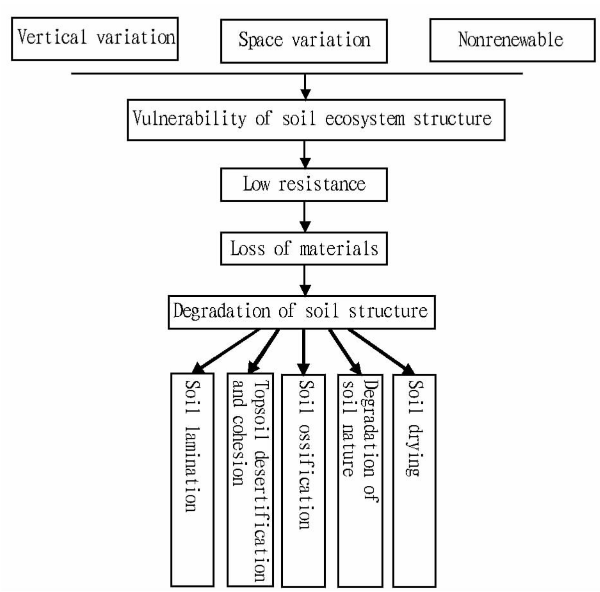

Fig. 1 Process and performance of soil structure degradation

exposed, shown as desertification. The degradation of soil structure is in fact a reverse process of soil formation. It has huge impact on soil development. It not only damages original soil property, but also damages entire soil mass. Such reverse development ultimately can bring the fertile land formed through thousands of years into infant soil whose absolute age and relative age are young. With damage of soil structure, the water, fertility, gas and heat conditions and adjustment function will be deteriorated and reduced accordingly.

3.2 Degradation of soil nutrient elements Reserves and effectiveness of nutrients in soil ecosystem are important factors influencing the system productivity, while the content of nutrients in soil bank and the degree of supply directly influence nutrient material cycle of the ecosystem.

Soil layer in southwestern karst regions is too thin, which directly influences growth and development of plant or crop root system. In the condition of basically same nutrient elements and content, the total amount of plant produced by thin soil is much less than that produced by thick soil; shortage of nutrient reserves will lead to ineffective nutrient supply[20]. The vertical variation of nutrient elements in soil profile is obvious; organic carbon, nitrogen and phosphorus elements take on direct correlation with content of organic matter. When the eroded soil is larger than material generated from soil formation action, it can not form normal soil profile. What's worse, the soil layer already formed will be constantly eroded. Consequently, material cycle of soil will become out of balance.

Soil evolution and plant succession are mutually influenced. Along with succession of plant, water content and nutrient cycle will also change, which will not only influence vegetation pattern and microorganism flora, but also influence yield of plants, and the humus accumulation and nutrient matter cycle will change accordingly. Researches have shown that there is significant direct correlation between organic matter, N, P and K and vegetation coverage degree in karst stony desertification areas; along intensification of degradation, the organic matter content in soil decreases sharply[21]. Change of land utilization can lead to change of surface vegetation and change of surface reflectance. As a result, it will influence plant withering and residues, also influence activities of soil microorganism. All of these will lead to redistribution of nutrient elements in soil system. After several decades since the cultivation transformation of agricultural and forestry ecosystem, the organic matter content in original forest soil still takes up the dominant position, but much components of organic matter originated from C3 plant are degraded, leading to low content of effective organic matter in plant nutrients. Land reclamation from destroying forest reduces proportion of organic matters that have higher activity, leading to reduction of soil fertility[22].

Vital vegetation in karst regions is mainly lithophytes, whose structure is relatively simple. The normal succession of regional ecosystem is slow and easy to be disrupted, and the self-adjusting ability is low, which is an important reason for vulnerability of karst ecosystem. Once destroyed, it is difficult to restore the original vegetation in karst regions. Surface exposure, one the one hand, makes the oil ecosystem lose the vegetation protection and deteriorates water loss and soil erosion; on the other hand, it is difficult to supplement organic matters of soil in natural state. The biogeochemical cycle with mutual feedback of soil and vegetation is weakened or discontinued, and the amount of production greatly drops. In consequence, nutrient element cycle that is relatively stable becomes out of balance, and soil nutrient elements are gradually degraded, as shown in Fig. 2.

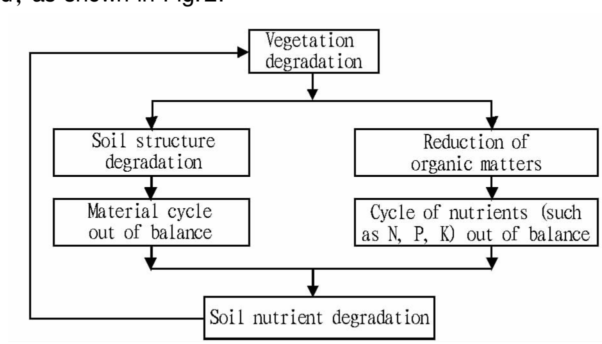

Fig. 2 Relationship between vegetation degradation and soil nutrient degradation

3.3 Other degradation The degradation evolution of every aspects of soil ecosystem is not isolated. Instead, it is a complex mutually interacting cycle. The soil drying, generally a secondary degradation accompanied with soil degradation, is the process of reduction of soil water storage capacity due to degradation of soil structure and change of soil environment. In the course of degradation of soil structure, soil clay particles and powders eluviate; soil capacity increases; porosity drops; water holding capacity greatly drops. At the same time, soil layer becomes thinner, soil temperature rises rapidly, and evaporation of water content in soil is deteriorated.

The types and content of soil microorganism in karst soil ecosystem are obviously less than that in other regions, and carbohydrate in the soil is major energy source of soil microorganism. Soil layer lamination, degradation of soil structure, and shortage of nutrient elements reduce activity range of metazoan and protozoan, impair flora diversity. Then, there will be changes of types of soil animals, diversity and breeding. As a result, it will lead to degradation of soil microorganism. Besides, microorganism is major force for conversion of organic matters. Various animal and plant residues will not be converted and utilized without participation of organism. Thus, the reduction of soil microorganism will significantly reduce conversion efficiency and speed of organic matters.

4 Conclusions

(i) Soil ecosystem in southwestern karst regions features strong space and time variation, nonrenewable feature and out of balance of soil nutrient cycle, as well as functional vulnerability. Once disturbed by natural or artificial activities, it is extremely possible to result in soil erosion, and lead to soil degradation.

(ii) The degradation of soil ecosystem in southwestern karst regions is mainly characterized by soil lamination, cohesion, ossification, and desertification resulted from out of balance of soil matter cycle; structural degradation of soil and vegetation degradation lead to shortage of supply of organic matters, N, P and K, and soil nutrients.

(iii) To recover degraded soil, transform and rationally utilize soil, we should take following measures. Firstly, stop the soil erosion and keep the total soil amount. Secondly, it is required to increase plant coverage, promote growth of forest and woods, and improve small environment. Besides, it is proposed to build ecosystem structure and biological species groups on the basis of interaction between soil, organism and environment, to keep the material cycle and energy conversion in the state of maximum utilization and optimal cycle, in the hope of harmonious development of soil, vegetation and organism and making the soil ecosystem develop in the direction towards benign cycle. Moreover, it is required to strengthen capital farmland construction, to practically protect cultivated land. Finally, it is recommended to pay close attention to cultivation and management of soil fertility, increase input in soil organic matters and nitrogen element, strengthen carbon and nitrogen material cycle, and promote continuous and stable development of soil quality.

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