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Recovery approach affects soil quality in fragile karst ecosystems of southwest China: Implications for vegetation restoration

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ABSTRACT

Natural regeneration and reforestation have been widely adopted to improve the degraded soil and promote ecological services in the karst regions of southwestern China. A better understanding the effects of different vegetation types on soil quality and the nutrient limiting factors is very important for each approach. In this study, a secondary forest (SF) and two plantations, *Eucalyptus maideni* F. V. Muell. (EM, exotic, deciduous broad-leaved) and *Pinus yunnanensis* Franch. (PY, native, conifer species), were selected in the karst graben basins of southwest China to explore the soil quality using Total Data Set (TDS) and Minimum Data Set (MDS) methods. The results indicated most soil parameters showed significant differences between the different recovery approaches. The TDS method is more precise than the MDS method, but the MDS method can also adequately represent the TDS method for the evaluation of soil quality with different vegetation restoration schemes. In the MDS method, soil organic carbon, available potassium, ammonium nitrogen, acid phosphatase, microbial metabolic quotient, and the Pielou index of the soil microbes were found to be the most important indicators for assessing soil quality. The pure plantation of PY had a negative effect on the soil quality, causing soil nutrient deficiency, compared to the SF and EM plantation, indicating that natural regeneration may be a more effective approach to the amelioration of soil quality in the karst areas. These findings provide an empirical and theoretical basis for the protection, restoration, and management of forest in the degraded karst areas.

1. Introduction

Karst landscape covers approximately 0.55 million km^2 in southwest China. Over the past several decades, excessive deforestation and the destruction of other vegetation cover caused the degradation of the ecosystem, alterations in community function, and acceleration of soil desertification (Lu et al., 2014). Thus, the ecosystem has not only experienced large variation in vegetation but also soil degradation is serious, which affects the soil quality in this area (Du et al., 2011; Jiang et al., 2014). The degraded ecosystem adversely affects the vegetation community, soil fertility, and ecological conditions, resulting in the abandoned bare land. The Chinese Government has recognized the seriousness of the problem, thus throughout the past two decades, several national-scale ecological restoration projects (e.g., the Green for Grain program and the Natural Forest Protection Project) have been implemented in these regions (Zhu et al., 2012; Shi and Han, 2014; Pang et al., 2018). Naturally recover and establishing plantations are the two major measures for restoring vegetation, and are vital to the structure and function of the karst ecosystem. Reforestation is a widely adopted method for restoring degraded sites and maintaining soil fertility, thus has been widely adopted in karst regions (Hu et al., 2016; Li et al., 2017).

Vegetation restoration with exotic, fast-growing tree species to restore degraded land is familiar in many countries (Teferi et al., 2016; Pang et al., 2018). One of the tree species considerable used in reforestation efforts in the karst regions is *Eucalyptus maideni* F. V. Muell.

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(EM). At the end of 2010, 3.68 × 10^7 ha of EM plantations have been planted across southwest China (Wu et al., 2014; Pang et al., 2018). However, EM plantations are a controversial problems and garner criticism concerning undergrowth and soil quality (Mekuria and Aynekulu, 2013). However, little relevant studies have been conducted with respect to the effects of EM plantations in karst areas. The other species commonly used for reforestation is *Pinus yunnanensis* Franch. (PY), a conifer species native to China. Due to its deep-reaching roots, high drought resistance, and tolerance of soils with poor fertility, it is widely used for afforestation projects in southwest China (Chen et al., 2012). However, research on PY plantations have focused on needle morphology, anatomical traits, and seedling traits, as plantations in such fragile regions remain scarce (Huang et al., 2016; Cai et al., 2016). At the same time, the area contains natural secondary forests (SF) that have not been managed. However, forest vegetation restoration not only depends on improving species diversity but also on ameliorating soil status (Fu et al., 2004). Different restoration methods influence soil status to various magnitudes, thus the comparison of the soil qualities under different restoration methods is of great significance to the success of vegetation restoration and management (Zhang et al., 2011b; Zhu et al., 2012; Ye et al., 2014; Hu et al., 2016).

Pedosphere is the most active layer of the earth's surface system, it is the core element connecting the atmosphere, hydrosphere, biosphere and lithosphere in the geosphere system (Fig. 1). Soil is an important natural resource, and its quality integrates physical, chemical, and microbiological attributes. Soil quality represents the capacity of a specific kind of soil to maintain biological productivity; sustain environmental quality and ecological balance; and promote organisms health; therefore, present and future management practices need to be improved and protected (Sharma et al., 2005; Shukla et al., 2006). However, soil quality could be influenced by land use type and human management practices. Therefore, better soil quality evaluation methods are vital to designing continuable forest management, improving primary productivity, restoring soil fertility, and promoting ecosystem service function. However, challenges maintain in evaluating soil quality because there is no established standards exist as soils varies greatly spatially and temporally (Ye et al., 2014). As proper assessment of soil quality requires a higher number of parameters, a minimum data set (MDS) with appropriate indicators can decrease the large number of indicators and sufficiently represent the total data set (TDS) (Andrews et al., 2002; Liu et al., 2014). So far, there is seldom information about soil quality assessment using synthetic index with the different reforestation modes in karst regions.

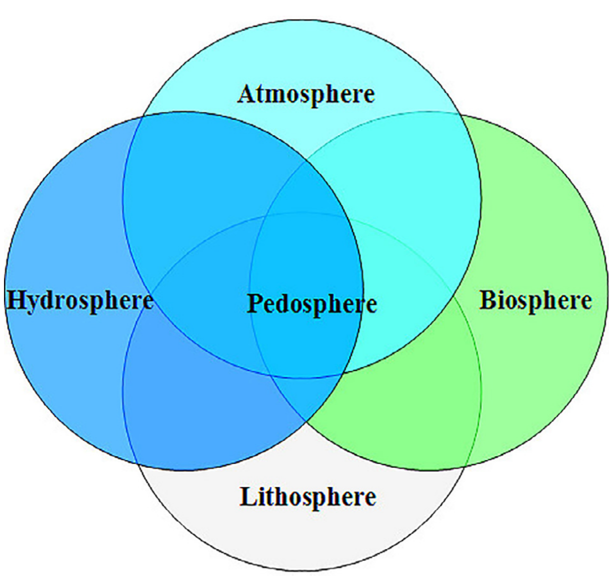

Fig. 1. The relationship between the pedosphere and other spheres.

Soil quality assessment have been widely used with physicochemical properties. However, these parameters usually variation slowly and lag behind in the ability to detect some reactions in soils (Poeplau et al., 2011; Six and Paustian, 2014). On the contrary, some soil microbial properties are susceptible to fluctuation, such as microbial biomass, enzyme activities and biochemical indicators, which are used in monitoring the quality and health of soils (Zhang et al., 2011b; Raiesi and Beheshti, 2015). In particular, biochemical and biological parameters, such as nutrient sources and sinks, participate in the major biogeochemical transformation of C, N, P, and S and contribute to soil structure, stabilization, and function (Cluzeau et al., 2012; Havlicek, 2012). Previous studies have shown that forest pattern management and transformation can lead soil microbial biomass, basal respiration, microbial quotients, and some enzymes and microorganisms are impressible indicators of variations (Zhu et al., 2012; Ye et al., 2014; Spohn and Chodak, 2015; Hu et al., 2016). Thus, the selection of appropriate indicators that accurately monitor the general change of soil quality following afforestation in karst regions is important.

Although various indicators and methods to assess soil quality have been explored in previous studies (Zhang et al., 2011b; Ye et al., 2014; Liu et al., 2014; Hu et al., 2016), there is no general assessment tool for measuring and quantifying soil quality at present, particularly in regions with a fragile environment. Therefore, it is imperative that evaluating soil quality in fragile areas such as in karst regions. In this research, we investigated two recovery patterns, natural recovery and plantations, in karst regions of subtropical China. Our objectives are to: (1) gain an insight into the effects of different vegetation restoration methods on the physicochemical and microbial properties of soils; (2) develop an synthetical assessment system for the soil quality that will determine which vegetation restoration type is most conducive to soil quality recovery; and (3) identify the constraints limiting the soil quality after reforestation in a fragile ecosystem. Our findings may provide a basis for more effective forest management systems in southwest China and other fragile regions.

2. Materials and methods

2.1. Study sites

This research was conducted at the Desert Ecological Research Station (102°54′E, 23°37′N) in Yunnan Province, southwest China. The region is located in subtropical monsoon climate. The mean annual temperature (MAT) is about 19.8 °C, mean annual precipitation (MAP) is about 805 mm, and there is a distinct dry season (from November to April) and wet season (from May to October). The region is characterized by a typical karst landscape with karst graben basins. The soil is mainly calcareous soil (Calcaric Cambisols, FAO), developed from a limestone base and characterized by a red color.

The soil and vegetation in the area is degraded due to the serious anthropogenic disturbances, therefore, resulting in large areas of abandoned bare land. Since 1996s, large-scale EM and PY plantations have become abundant in this region and have been used to restore the degraded ecosystem due to the “Grain for Green” project. The subtropical primary forests in the region were largely destroyed by humans, so naturally regenerated SF have appeared in this region. The stand age was confirmed from interviews with the local farmers (Table 1).

2.2. Sample collection and pretreatment

In June 2016, three vegetation types were selected: SF, EM plantations, and PYplantations. In order to ensure the comparability, three replicate plots were selected for each vegetation type. The size of each plot was 400 m^2 (each with dimensions of 20 × 20 m). In total, nine plots were chosen for field observation and sampling. The soils in the study areas were developed from limestone. For this reason, we