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Research article

Responses of soil nutrients and microbial communities to three restoration strategies in a karst area, southwest China

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ABSTRACT

Ecological restoration is widespread in the karst region, southwest China, but the impacts of different restoration strategies on soil fertility indices have rarely been compared. Here soil nutrients and microbial communities were measured 16 years after agricultural abandonment in a karst area, southwest China. Three restoration strategies were included, i.e., i) restoration with an economic tree species *Toona sinensis* (TS), ii) restoration with Guimu-1 hybrid elephant grass (GG), iii) restoration with a combination of *Zenia insignis* and Guimu-1 hybrid elephant grass (ZG). Cropland under maize-soybean rotation (CR) was used as reference. Soil organic carbon level was more than doubled in TS, and that in GG and ZG was elevated by about 50% relative to CR. Soil total nitrogen concentration in GG was not significantly different from CR, but that in TS and ZG was increased by 93% and 55% relative to CR. Similar to nitrogen, soil total phosphorus concentration in GG was not changed relative to CR, but that in TS and ZG were significantly increased. Microbial biomass carbon and nitrogen concentrations were significantly increased in TS and GG by 124% and 82%, respectively, compared to CR, but those in ZG and CR were similar. The abundance of total PLFAs (phospholipid fatty acids) was significantly increased by 55–69% following agricultural abandonment, and there was no significant difference among the three restoration strategies. The patterns of the other microbial groups and the ratio of fungal to bacterial (F:B) PLFAs were largely similar to that of total PLFAs. Soil organic carbon was identified as the primary factor affecting the abundance of soil microbial communities. Our findings suggest that the three restoration strategies, particularly TS are efficient in improving soil fertility.

1. Introduction

Ecological restoration has received worldwide attention due to its vital roles in carbon (C) sequestration, biodiversity conservation, desertification prevention and soil fertility improvement of degraded lands (Baer et al., 2015; Baker and Eckerberg, 2016). A target to restore at least 15% of the degraded lands globally has been proposed by United Nations Convention on Biological Diversity (Asmelash et al., 2016). However, there is evidence showing that many restoration projects are failed or get limited success (Asmelash et al., 2016). In this sense, it is crucial to monitor the dynamics of ecosystem structures, functions and processes during ecological restoration, including soil fertility indices such as soil organic C (soil C hereafter), soil total nitrogen (TN), soil total phosphorus (TP), and soil microbial communities (Diacono and Montemurro, 2012). Soil C is a perfect proxy for judging whether degraded lands have improved, as increase in soil C benefits the improvement of water holding capacity, nutrient retention capacity, soil structure and soil biological quality (Lal, 2004; Diacono and Montemurro, 2012). Soil TN and TP are the major limiting nutrients of ecosystem productivity and play key roles in ecosystem restoration or succession (Zhang et al., 2015; Wen et al., 2016). For example, failure in afforestation is often caused by insufficient supply of nutrients, particularly N to plant growth, and secondary succession following agricultural abandonment may remain stagnant due to insufficient soil N availability (Mudge et al., 2014; Wen et al., 2016).

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Soil microbial communities play key roles in soil biogeochemical cycles and exerts direct and indirect effects on the development of plant communities (Wardle et al., 2004). Additionally, soil microbial communities can be used as an integrated measure of soil health or fertility due to their important roles in soil nutrient cycling (Suzuki et al., 2005; Iyyemperumal and Shi, 2007; Trivedi et al., 2016). Many factors have been found to affect the abundance, composition and structure of soil microbial communities, including substrate quantity/quality, soil pH and plant diversity and composition (Wardle, 2006; Drenovsky et al., 2010). These factors change following agricultural abandonment or during ecological restoration (Zornoza et al., 2009; Baer et al., 2015). Different restoration strategies, e.g., restoration with different plant species with or without management, may be considered when restoring a given degraded area. As different tree species or their combinations may have differential effects on substrate quantity and quality, rhizo/mycorrhizospheric chemistry, and other soil properties (Russell et al., 2007; Frouz et al., 2013), they may induce distinct profiles of soil microbial communities (Prescott and Grayston, 2013). For example, distinct bacterial and fungal communities under different tree species have been found either in common garden experiments or natural stands (Lejon et al., 2005; Thoms et al., 2010). The distinct microbial communities have great implications for soil organic matter (SOM) transformations. For example, the decomposition pathways by fungi and bacteria are much different (Heuer et al., 1997; Bailey et al., 2002; Ferris et al., 2004). SOM with high cellulose and lignin content and high C:N ratio are likely decomposed via fungal-dominated “slow” pathways, while moist, N-rich tissues are mainly decomposed via bacterial-dominated “fast” pathways (Ferris et al., 2004). In addition, soil C fractions mediated by fungi is likely more stable relative to those mediated by bacteria (Bailey et al., 2002). Consequently, ecological restoration with different plant species may impact both soil biotic and abiotic properties, which in turn may affect the dynamics of aboveground communities of the restored systems.

Karst ecosystems are widely distributed over the Earth's land surface, including southwest China (Wen et al., 2016; Li et al., 2017a, 2017b). In the past, a large portion of the karst lands in southwest China has been degraded due to intensive human disturbances especially agricultural activities. Most of the seriously degraded lands have been subject to ecological restoration due to the implementation of several ecological restoration projects since the end of 1990s (Wen et al., 2016; Li et al., 2017a, 2017b). Nevertheless, the impacts of different restoration strategies on soil nutrients and microbial communities have rarely been compared in the karst region. In the present study, soil nutrients and microbial communities (characterized by phospholipid fatty acid (PLFA) method) under three commonly adopted restoration strategies in the karst area of southwest China were compared, i.e., i) restoration with an economic tree species *Toona sinensis* (TS), ii) restoration with Guimu-1 hybrid elephant grass (GG), and iii) restoration with a combination of *Zenia insignis* and Guimu-1 hybrid elephant grass (ZG). Cropland was used as reference. Our previous study showed that soil C stock in TS, and soil TN stocks in both TS and ZG were significantly increased relative to CR when observed in 2014 (Xiao et al., 2017). We hypothesized that the patterns of soil C and TN in the present study (observed in 2017) would be similar to those observed in 2014 (**Hypothesis I**). On the other hand, fungi are sensitive to disturbance, e.g., tillage, but bacteria can rapidly adapt to frequently changing soil environment (Drenovsky et al., 2010; Ma et al., 2015). Subsequently, the abundance of fungal community may increase more pronouncedly relative to that of bacterial community when the disturbance ceases. We therefore hypothesized that the fungal to bacteria PLFA (F:B) ratio would increase following agricultural abandonment (**Hypothesis II**).

2. Materials and methods

2.1. Site description

This study was conducted at Guzhou catchment (107°56′-107°57′ E, 24°54′ E-24°55′ N) in Guangxi Zhuang Autonomous Region, southwest China. This region is located in the subtropical humid forest life zone with a monsoon climate. Mean annual air temperature is 15.0–18.7 °C, with the lowest monthly mean in January (3.4–8.7 °C) and the highest in July (23.0–26.7 °C). Mean annual precipitation ranges from 1530 to 1820 mm with a distinct seasonal pattern. The period from April to August is the wet season and that from September to March is the dry season. The area is characterized by a typical karst landscape with gentle valleys flanked by steep hills. The soil is calcareous lithosols (limestone soil) according to the FAO/UNESCO classification system (Wen et al., 2016; Li et al., 2017a). Averaged soil depths vary from 0 to 80 cm in the valley, and from 0 to 30 cm on the slopes.

Guzhou catchment has an area of 10.2 km^2 and an elevation ranging from 375 to 816 m above sea level (Zhang et al., 2015; Xiao et al., 2017). Before the 1980s, this catchment was seriously disturbed by deforestation and cultivation on the slopes. Under the support of several ecological restoration project, most of the degraded cultivated lands over slopes were abandoned and recovered under different restoration strategies in early 2000s.

2.2. Experimental design

The detailed description of the experiment was presented elsewhere (Xiao et al., 2017). The experiment site used to be a cropland under maize-soybean rotation before 2002 and was distributed over the bottom area of a slope of about 20°. The major objective of the experiment was to investigate the temporal dynamics of soil properties and plant community following agricultural abandonment. The experiment adopted a completely randomized block design with five treatments (four restoration strategies and a cropland as reference) and three replications. Each replication plot has an area of 20 m × 20 m. However, one plot of the restoration strategy “Spontaneous regeneration (SR)” was burned occasionally in December 2016. Therefore, this restoration strategy (SR) was not included in the present study. The three restoration strategies included in the current study are described below:

i) Restoration with *Toona sinensis* (TS), an economic tree species. The tender shoot in spring is a popular vegetable in China.
ii) Restoration with Guimu-1 hybrid elephant grass (GG), a hybrid of elephant grass and *Pennisetum alopecuroides*. This grass is perennial and has high biomass production, harvested for 3–4 times per year and used as fodder for beef.
iii) Restoration with a combination of *Zenia insignis* and Guimu-1 hybrid elephant grass (ZG). *Zenia insignis* is a native tree species with the leaves used as additive to the fodder for beef. The Guimu-1 hybrid elephant grass is usually harvested for 3–4 times per year and used as fodder for beef.

The cropland (CR) under maize-soybean rotation was used as reference and managed using a typical manner by the native farmers. Fertilizer was applied in the cropland at a rate of 450 kg ha^{-1} yr^{-1} with compound fertilizer ($N:P_2O_5:K_2O$ = 15:15:15) in March. The field was tilled twice in March and July, respectively, to a depth of 20–30 cm. No fertilization and tillage were applied in the three restoration treatments.