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Original article

Microbial responses to erosion-induced soil physico-chemical property changes in the hilly red soil region of southern China

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ABSTRACT

Water erosion can significantly alter soil physicochemical properties. However, little is known about soil microbial responses to erosion-induced soil physicochemical properties changes in the hilly red soil region of southern China. This research was conducted to determine the impact of water erosion on soil biological properties and the relationships between microbial community compositions and physico-chemical parameters. Soil samples of the 0–10 cm layer in one fallow depositional site and five erosional sites (including a *Pinus massoniana* Lamb. site, *Elaeocarpus decipiens* Hemsl. site, *Michelia maudiae* Dunn site, *Cinnamomum bodinieri* Levl. site and *Lagerstroemia indica* Linn. site) were collected. Denaturing gradient gel electrophoresis (DGGE) profiles of 16S rDNA were generated to describe the influence of soil erosion on bacterial communities. The results showed that the depositional site had greater microbial biomass and enzyme activities compared to most erosional sites. Redundancy analysis suggested that all physico-chemical parameters together accounted for 79.6% of the variation in bacterial community ($P < 0.05$). Among these parameters, dissolved organic carbon (DOC) showed a predominant effect on the variation (19.3%; $P < 0.05$), while soil organic carbon (SOC) and total nitrogen individually contributed to only 3% and 2.5% of the variance in bacterial community, respectively ($P > 0.05$). These results indicated that soil deposition is beneficial to enhance soil microbial biomass, while soil erosion is in reverse. DOC is a more important factor influencing soil biological characteristics in comparison to other measured physicochemical parameters. Relative to the quantity of SOC, the quality of C is more important in influencing soil biological properties.

1. Introduction

Soil microorganisms play important roles in soil ecosystems by regulating the decomposition of organic matter, the formation of humus and cycling of nutrient elements [1,2]. In addition, soil microbes release various enzymes which have widely been used as indicators for soil biological properties and sustainability of ecosystems [3,4]. Soil enzymes can catalyze nutrient recycling in forms available for plants and other organisms and mediate most soil biological processes. Thus, soil microorganisms and enzymes are the main driving force in soil biochemical processes [4,5]. Compared with soil physical and chemical properties, both soil microorganisms and enzymes are more sensitive to the environmental change and disturbance and can better indicate current soil environmental conditions [6]. Soil erosion is the most widespread form of soil degradation and represents one of the most important but poorly quantified environmental problems [7,8]. Soil erosion is

Abbreviations: DCA, detrended correspondence analysis; DOC, dissolved organic carbon; MBC, microbial biomass carbon; PCA, principal component analysis; PCR-DGGE, polymerase chain reaction-denaturing gradient gel electrophoresis; RDA, redundancy analysis; SOC, soil organic carbon; TN, total nitrogen.

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usually coupled with changes in local soil properties and biological processes, and can affect soil carbon dynamics through many different ways [9–11]. For example, erosion-induced soil aggregates destruction can strongly impact the stability of carbon in soils.

In the past decades, substantial research efforts were performed to characterize the impact of water erosion on the distribution of sediment as well as the associated carbon within landscapes [12–14], showing that water erosion disturbed carbon-rich topsoil and preferentially removed the finer particles and associated soil organic carbon (SOC) from the eroding slope to the depositional site [15–17]. However, little information is available on the response of soil microbial community to changes of erosion-induced physicochemical properties in the hilly red soil region of southern China. Altered SOC, total nitrogen (TN), and labile organic carbon (e.g., dissolved organic carbon) storage in soils may induce significant effects on the composition and activity of microbial communities. Previous research confirmed that among all organic matter fractions, the labile dissolved organic carbon accounted for the largest amount of variation in microbial functional diversity [18]. While in the study by Fierer and Jackson [19], the differences in the diversity and richness of soil bacterial communities were largely explained by soil pH. A complete and systematic understanding of soil microbial responses to physicochemical properties changes is still lacking. Previous research that addressed the microbiological properties were mainly restricted to the effects of field management, fertilization and vegetation patterns, while the impact of water erosion on soil biological properties was rarely examined.

In this study, we hypothesized that soil deposition is beneficial to enhance soil biological activities, and the heterogeneity in soil biological characteristics between erosional and depositional sites is closely correlated to erosion-induced soil physicochemical properties changes, particularly to labile organic carbon. To test our hypotheses, the spatial variabilities of soil microbial diversity and enzyme activities were studied in a closed basin with six different vegetation types in the hilly red soil region. Due to high temperature and frequent high-intensity thunderstorms, accelerated soil erosion has become widespread there. In addition, PCR-DGGE was applied to intuitively discern the dynamic of microbial communities in different sites [20]. Information on soil microbial community composition in combination with soil enzyme activities informed us the long-term effects of soil erosion on organic matter decomposition and maintenance in both erosional and depositional sites of mountain ecosystems. The main objectives of this study were to (a) investigate the distinctions of soil biological properties in erosional and depositional sites; and (b) quantify the relationships between soil physicochemical parameters and microbial communities.

2. Materials and methods

2.1. Experimental sites

The study was conducted at the Soil and Water Conservation Monitoring Station of Shaoyang City, Hunan Province, China (Fig. 1). This region has a typical subtropical monsoon climate, with annual mean minimum and maximum precipitations of 1218.5 mm and 1473.5 mm, respectively. The maximum rainfall usually occurs in June and the minimum in December. The mean annual temperature is 17.1 °C, and the hottest month is July with an average temperature of 26.6 °C. The soil in the study area is typically Quaternary red clay, which is extremely eroded and characterized by low pH and insufficient available nutrients for vegetations [17]. Soil with clay to loam texture was classified as Ultisol in U.S. Soil Taxonomy. Topographically, the slopes are generally <8°, but are usually longer than 100 m. According to the main vegetation types covering the soil surface, the study watershed can be divided into six sites: the *Elaeocarpus decipiens* Hemsl. site (hereafter termed EE), *Cinnamomum bodinieri* Levl. site (termed CE), Chinese pine (*Pinus massoniana* Lamb.) site (termed PE), *Lagerstroemia indica* Linn. site (termed LE), *Michelia maudiae* Dunn site (termed ME), and the fallow grass site (termed GD), respectively (Fig. 1). These vegetation types are widespread in southern China.

2.2. Soil sampling

Soil samples were taken from the top 10 cm of the soil profile in each of the field sites in May 2014. Before collecting soil samples, sampling plots (40 × 40 cm) were established at each site. Three soil core samples were collected using a soil auger (7 cm inner diameter) within each sampling plot and then mixed together to make one composite sample. Five separate sampling plots were selected in each erosional site as five replicates, and three sampling plots were chosen in the depositional site due to its relatively small field area (Fig. 1). These plots were considered to be independent of each other as the distance among them exceeded the spatial dependence of most soil nutritional and microbial variables. After removing the fine roots and stones, each soil sample was divided into two equal parts, one of which was stored instantly at −20 °C in order to analyze the soil microbial properties. The other part of the sample was air dried at room temperature to determine the soil physicochemical properties.

2.3. Laboratory analyses

2.3.1. Measurement of physicochemical parameters

Soil physicochemical properties analyses were performed using standard soil test procedures. Subsamples of sieved soils (passed through 0.25 mm sieve) were transported to the Hunan Academy of Agricultural Sciences for SOC and TN analysis. SOC and TN were determined with the dichromate oxidation method of Walkley and Black [21] and the Kjeldahl method [22], respectively. For determination of DOC content, the field-moist soil samples (equivalent to 15 g oven-dried soil) were extracted with 60 ml of 0.5 M K_2SO_4 (soil to solution ratio 1:4) for 1 h. After centrifuging at 4000 rpm for 25 min, the supernatant was filtered through a 0.45 μm membrane filter and measured in a Total Organic Carbon Analyzer (TOC-VCPH, Shimadzu, Japan) [18]. The ^{137}Cs activity was measured using a hyperpure Li-drifted Ge detector coupled to a DSPec multichannel gamma-ray spectrophotometer (GMX50, PerkinElmer, USA) with an average counting time of over 20,000 s.

2.3.2. Soil biological characteristic analyses

The chloroform-fumigation extraction method was used to estimate soil microbial biomass carbon (MBC) [23,24]. Field moist soil samples (approximately 10 g oven-dry soil) were fumigated with ethanol-free chloroform for 24 h at 25 °C under dark condition and the control samples of equal weight were not fumigated. Both fumigated and un-fumigated samples were extracted with 40 ml 0.5 M K_2SO_4 solution (soil to solution ratio 1:4) and shaken at 300 rpm for 30 min, the extract was filtered through a 0.45 μm membrane and then measured in a Total Organic Carbon Analyzer (TOC-V_{CPH}, Shimadzu, Japan). Biomass C was calculated as follows:

$$MBC = E_C / K_{EC} \quad (1)$$

where E_C = (organic C extracted from fumigated soil) − (organic C extracted from non-fumigated soil) and K_{EC} = 0.45 which is the scale factor to convert E_C to MBC [25].

To examine the effect of soil erosion on enzyme activities, the