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The effects of erosion on the microbial populations and enzyme activity in black soil of northeastern China

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ABSTRACT

Soil erosion may deteriorate soil microbial ecosystems, and assessing the impacts of soil erosion on soil micro-biological properties is important for eroded-soil restoration. Based on the simulated erosion plots with treatments of eight erosion depths (0, 10, 20, 30, 40, 50, 60 and 70 cm) and two sub-treatments of no fertilizer and chemical fertilizer situated in black soil region, northeast China, soil samples of the 0–20 cm layer in each plots were collected and several key soil biological parameters were determined. The results indicated that the values of all the variables of soil micro-biological properties had a linearly decreasing trend with increasing erosion depths. From erosion depth of 0–70 cm, the soil microbial biomass C (MBC), microbical biomass N (MBN), numbers of bacteria, mold, actinomyces, azotobacter, phosphorus bacteria, potassium bacteria, and catalase, urease, β-glucosidase, cellulase activities decreased by 93.4%, 93.1%, 87.7%, 78.2%, 82.9%, 72.7%, 79.7%, 79.6%, 91.3%, 89.8%,91.7% and 69.5%, respectively for fertilized plots, and 94.8%, 78.2%, 89.7%,59.0%, 92.3%, 72.7%, 79.7%, 78.4%, 90.0%, 87.9%, 92.6% and 75.0%, respectively, for unfertilized plots. There were significant correlations between soil organic matter (SOM), total N (TN) and soil micro-biological properties. Chemical fertilization increased available P (AP) ($P < 0.001$) and SOM ($P < 0.05$) significantly, but had no significant effect on MBC, MBN, microbial quantities and enzyme activities. The results showed that local conventional chemical fertilization did not enhance soil biological status and was not able to counterbalance the fertility loss incurred by soil erosion, and also suggest that protective measures to improve soil biological properties should be taken immediately.

1. Introduction

Soil microbes play crucial roles in soil ecosystems by regulating the decomposition of organic matter, the formation of humus, and cycling of nutrient elements, while soil enzymes catalyze or mediate most soil biological processes; thus, soil microbes and enzymes are key components and the main driving force in soil nutrient cycling and energy flow [1,2]. Both soil microbes and soil enzymes are key components of soil quality and health [3], and compared with soil physical and chemical properties, are more sensitive to environmental change and disturbance, and indicate the soil environmental conditions promptly and precisely [4]. Previous studies have revealed that crop types, fertilization, and field management can profoundly influence soil microbial status and enzyme activities [5–7]. Soil erosion, one of the most critical current environment problems, is the main process leading to soil degradation worldwide [8]. Soil erosion may dramatically alter microbial properties and enzyme activities. Research has shown that microbial counts, biomass, diversity, and enzyme activity fall drastically during soil erosion [9–12].

Northeast China's fertile black soil region has been the main commodity grain and soybean production area with its arable land and favorable environment, but after decades of reclamation without proper conservation measures, accelerated soil erosion has become widespread there [13]. Previous research related to soil microbial properties in the black soil region has concentrated on the effects of cropping patterns, fertilization, and field management [14–16]. However, one of the few research studies to discuss the effects of soil erosion on soil microbial properties in the black soil [17] investigated these effects at the Hailun Field Experimental Station by removing the upper 0, 10, and 30 cm of soil to simulate soil erosion. Obviously, scalping a soil layer at one point in time is quite different from the erosion process, so the results may not be convincing. Also, the black soil layer in this region may be as thick as 70 cm, so changes in microbial properties at different erosion depths may be different; the soil microbial structure and functions at different erosion depths may vary, leading to different soil fertilities and properties. In this sense, conservative measures should be adopted in accordance with erosion depths.

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This study uses artificial soil erosion plots to investigate changes of some microbial properties which fully imitate natural erosion and tillage activity, and establishes the quantitative relationships between soil microbial properties and soil erosion depth while evaluating the effects of chemical fertilization on soil microbial properties. The results provide insights into the biological mechanisms of soil degradation incurred by soil erosion in the black soil region, and encourage soil quality assessment and soil fertility enhancement.

2. Materials and methods

2.1. Site description

The study was conducted as part of an on-going long-term soil erosion and productivity experiment, started in 2005, at the Field Experimental Station (48°59′55″N, 125°17′35″E) of the State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University. The station is located at the Heshan Farm of the Jiusan Division of the General Farm Management Bureau of Heilongjiang Province, China. The semi-humid continental monsoon climate of the cold-temperate zone has an average annual precipitation of 500 mm and a mean annual temperature of 0.4 °C. Topographically, the slopes are generally <8° but are usually longer than 300 m; in addition, most farmland is located on the slopes and the ridges in the fields are always parallel to the slopes. The natural vegetation consists of temperate humid meadow grasses, but after decades of reclamation, most natural vegetation has disappeared and been replaced by crops including soybean, maize, and wheat. The soil is typically a black soil (mollisol), which is susceptible to erosion. Nature conditions coupled with anthropological activities have led to severe soil erosion in this area.

2.2. Experimental design

2.2.1. Stimulation of eroded soil

Soil erosion is a slow process of dilution. Every year, when the upper layer of top soil from the cultivated horizon is denuded, a corresponding layer from the plow pan is turned up and mixed with the remaining soil within the cultivation horizon. This process continues from year to year and results in overall depletion of fertile soil depth. As a result, the thickness of the cultivated horizon is always the same, but the amount of original top soil decreases while the amount of subsoil in the soil mixture increases, resulting in a loss of fertility over time. To simulate soil erosion on cultivated land, the integrated processes of natural soil erosion and tillage activity must be considered.

In summary, the original soil profile from the surface to the parent material horizon is divided into h_0, h_1, h_2, h_3,. . ., h_n, to give a total of $n+1$ layers, where h_0 is the original cultivated horizon. Then, after n years of erosion, the remaining thickness (h'_i) of the original h_i layer in the cultivated horizon is:

$$h_i' = h_i \times \left(1 - \frac{d}{m}\right)^n \quad (1)$$

where h_i is the thickness of the original h_i layer (cm), h'_i is the remaining thickness in the new cultivated horizon of the original h_i layer (cm), d is the average annual erosion depth (cm), and m is the thickness of the cultivated horizon (cm). After n years of erosion, the component of the cultivated horizon m is:

$$m = h_0 \times \left(1 - \frac{d}{m}\right)^n + \cdots + h_i \times \left(1 - \frac{d}{m}\right)^{n-i} + \cdots + h_{n-1} \times \left(1 - \frac{d}{m}\right) + h_n \quad (2)$$

Based on the tillage depth and soil loss rate of the study area, the cultivated layer m is set at 20 cm, and the soil loss rate is 0.5 cm a^{-1}. The simulated erosion depths are 0, 10, 20, 30, 40, 50, 60, and 70 cm respectively, so the original soil profile is divided as follows: h_0 = 0–20 cm, h_1 = 30–40 cm, h_2 = 40–50 cm, h_3 = 50–60 cm, h_4 = 60–70 cm, h_5 = 70–80 cm, h_6 = 80–90 cm. Using Eq. 2, the soil components of the cultivated horizon m can be calculated. For example, it took 20 years for the erosion depths to reach 10 cm, and by that time h'_0 is 12.05 cm, and the h'_1 is 7.95 cm. For more details of the principle and simulation process of the eroded soil profile, see Wang et al. [18].

2.2.2. Field plots and treatment

The field plots were constructed in 2005, located on a lower back slope of a 25-ha farm with a slope of approximately 2°. Eight erosion levels, 0, 10, 20, 30, 40, 50, 60, and 70 cm, were stimulated, and each erosion level had two sub-treatments, no fertilizer, and locally conventional fertilizer. Each sub-treatment had three replications, which resulted in 48 erosion–productivity sub-plots. Each 4 m × 4 m plot had an effective area (crop area) of 16 m^2. Using a randomized block experimental design, the plots were divided into three blocks. Within each block, 16 experimental plots including eight erosion levels (0, 10, 20, 30, 40, 50, 60 and 70 cm) and two sub-treatments (no fertilizer and conventional fertilizer) were laid out in a random pattern.

Crop rotation (soybean–soybean–soybean–soybean–spring wheat) has been practiced at this experimental site since 2005. The planting density was 450,000 seeds per hectare, and six ridges of soybean (North Sinkiang 96-711 in 2011) were sown in each plot. All fertilized plots received an annual fertilization of 46.2 kg N ha^{-1}, 60.0 kg P ha^{-1}, and 13.8 kg K_2O ha^{-1}, applied simultaneously at sowing.

2.3. Soil sampling

Soil samples were taken from the top 20 cm of the soil profile (cultivated layer) in each of the field plots in September 2011, after the harvest of the soybean. The sample points were on the middle four ridges, and for every ridge, three points were distributed uniformly, with an interval of 1 m, so that each sample was the mixture of 12 sub-samples. Each sample represented each plot, and thus a total of 48 samples were collected. After carefully removing the fine roots, organic material, and stones, each sample was divided into two parts. One part was air dried for the measurement of soil chemical properties and the other was sieved (2 mm) and kept at 4 °C in sealed polyethylene bags for analysis of soil biological properties.

2.4. Soil analysis and methods

The measures of MBC and MBN were determined by the chloroform fumigation–extraction method [19]; the microbial counts are determined by the dilution plate count technique. For bacteria, mold, and actinomycetes, the following media were used: beef extract peptone medium, potato sucrose medium, and Gause's I medium, respectively; for azotobacter, phosphorus bacteria, and potassium bacteria, the following media were used: Ashby medium, inorganic phosphorus medium, and silicate medium, respectively [20]. Soil enzyme activities including catalase, urease, β-glucosidase, and cellulase were determined following the methods proposed by Guan (1986) [21], and the activities were expressed as milliliters, 1 mmol/L $KMnO_4$/g h (37°C), NH^+_4–N μg/g h (37 °C), μg *p*NP/g h (37°C), and μg glucose/g h (37°C), respectively.

Soil organic matter (SOM) was determined by the K_2CrO_7 titration method. Soil total nitrogen (TN) was determined by the semi-micro-Kjeldahl method. Soil total phosphorus and total potassium were digested by HF–$HClO_4$ and determined by molybdenum blue spectrophotometry and flame photometry, respectively. Bulk density