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Comparison of crop productivity and soil microbial activity among different fertilization patterns in red upland and paddy soils

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ABSTRACT

Soil enzyme activity and microorganism community can be changed through different long-term fertilization patterns. However, the effect of different fertilization practices on soil microorganisms might differ among crop systems. The objective of the study was to reveal the change of soil enzyme activity and soil microorganism community in different fertilizations both in upland and paddy soils. Therefore, based on long-term fertilization experiments in upland soil started in 1986 and adjacent paddy soil experiment commenced in 1981, with both consisting of 4 treatments: Control (no fertilization), N (only nitrogen fertilizer), NPK (nitrogen, phosphate and potassium fertilizers) and NPKM (nitrogen, phosphate and potassium fertilizers plus organic manure), grain yield, soil fertility, activities of soil urease, catalase, acid phosphatase, microorganism community (the number of bacteria, fungus and actinomycete) were analyzed. The result showed that: the highest grain yield was attained under the application of chemical fertilizers plus manure, as compared with Control, NPKM significantly increased the grain yield by 908.63% in corn and 118.80% in rice ($p < 0.05$). Meanwhile, NPKM treatment increased significantly soil organic matter and nutrient contents in upland and paddy soils. Interestingly, there was no significant difference in soil pH among all the treatments of paddy soil, but in upland, NPKM increased pH in comparison to Control by 23.06% (1.15 units of pH). Compared with Control, soil urease, catalase activities, bacteria and actinomycete numbers of NPKM were increased by 321.39%, 129.64%, 229.79%, 85.81% in upland soil, and 25.11%, 251.12%, 292.83%, 196.34% in paddy soil. However, in paddy soil, the soil acid phosphatase activity of Control, NPK and NPKM treatments were higher than upland soil by 34.87%, 44.81%, 52.73% and 30.11%. Then, the soil fungus and actinomycete numbers of paddy soil were lower than upland soil by 20.20% and 88.29%. Therefore, it indicated that long-term application of chemical and organic fertilizers delivered highest productivity in both experiment but the effect of fertilizer practices differed between land uses.

1. Introduction

Red upland soils and paddy fields play important roles in grain production in Southern China and the entire country. However, the soil fertility of these soils has been decrease over the years due partly to intensive application of fertilizers, less manure, shallow plough layer and so on. Despite decrease in soil fertility there is no increase in grain yield, and it is same result even though using high-yielding varieties and application of chemical fertilizers. But the excessive and continuous application of chemical fertilizers has resulted in soil acidification [1,2], soil structure degradation [3,4], pollution of water bodies [5,6] and many adverse effects on the environment.

The soil physical, chemical and biological properties of red upland and paddy soils differ significantly from each other [7–9]. In generally, the red upland soil is characterized by low productivity and high risk of erosion resulting from intensive weathering aggravated by inappropriate utilization [10]. In contrast, the paddy soil usually contained higher soil organic matter (SOM) than upland soils within the same geomorphic unit [11,12], although paddy soil was formed by planting rice of long time in red soil [13]. Meanwhile, the soil moisture in paddy soil was often changed by wetting and drying, *Yuan* et al. [14] found that the abundance and diversity of autotrophic bacteria in soil varied among different land use types (natural forest, paddy rice, maize crops, and tea plantations). It was found that SOM and total nitrogen (TN) contents were the major factors when converting soil management systems. *Chen* et al. [15] demonstrated that the lower dissolved organic matter (DOM) content in the paddy soil compared with that in the upland soil is probably factor by the less complex components and structure of the DOM, although SOM content in paddy soils is higher than that in upland soils. However, moisture was not the key factor in determining differences between the two agricultural soils under contrasting management regimes, despite the fact that moisture strongly controls DOM fate.

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In previous studies, the difference in soil microorganisms between red upland and paddy soil were mainly due to contrasting management regimes [7,8,14,15]. It is recognized that organic manure plus chemical fertilizers could increase grain yield, soil fertility and microbial number [16–18], and the increments of soil properties were not the same in different soil types because annual average temperature, relative humidity and crops were attributes closely correlated with microbial abundance [19,20]. *Yan* et al. [12] investigated that SOM stock and physical fractions responded to C input under different fertilization practices, they indicated that paddy soil may sequester more SOC, with higher efficiency, than upland soil does. However, little attention was paid to change of soil enzyme activity and soil microorganisms in different fertilization managements both in upland and paddy soils. In this study, we investigated two long-term fertilization experiments with the same treatment design. The red upland soil experiment started in 1986 while the paddy soil, adjacent to upland soil experiment, commenced in 1981. They both consist of four fertilization treatments including no fertilization as a control (Control), nitrogen fertilizer alone (N), combined with nitrogen, phosphorus, potassium fertilizers (NPK), combined with organic manure and NPK (NPKM). The objectives of the study were to investigate: (i) how soil enzymatic activity, bacteria, fungus and actinomycete numbers respond to different fertilization practices, especially application of chemical fertilizers with manure; and (ii) comparison of soil enzymatic activity, bacteria, fungus and actinomycetes numbers in same fertilization between the two contrasting crop systems (red upland and paddy soils). Understanding the effect of different fertilization practices on soil microorganisms will help to develop sustainable agriculture practices.

2. Materials and methods

2.1. Site description

The two long-term field fertilization experiments on upland and paddy soils are located at Jiangxi Institute of Red Soil, Jinxian county of Jiangxi Province, China (28′21 N, 116′10 E). This area has a typical subtropical climate with a mean annual rainfall of 1727 mm, of which about 38% falls from March to early July and about 14% falls from late July to early November. The uneven distribution of rainfall causes a strong seasonal drought in summer and/or early autumn. The annual average temperature is 18.1 °C with an average of 262 frost-free days per year.

2.2. Experimental design and treatments

Experiment 1: The long-term fertilization experiment on upland soil was initiated in 1986. Peanut (*Arachis hypogaea L.*) was growing on the soil prior to the beginning of the experiment for over 10 years, and pig manure was often applied in this field. The crop rotation consists of early maize (*Zea mays L.*) from April to July, late maize from July to October, and winter fallow from November to April of the next year. Prior to the start of the experiment, the soil was classified as red soil in the Chinese soil classification or as typical plinthosols (IUSS, 2006). The parent material is quaternary red clay with dominant kaolinite mineral. Before the experiment, the chemical properties of the soil in the plough horizon (0–20 cm) was as follows: pH (H_2O) of 6.0, 16.19 g kg^{-1} SOM, 0.98 g kg^{-1} total N, 1.42 g kg^{-1} total P and 15.8 g kg^{-1} total K. The proportion of sand, silt and clay was 30.1%, 34.5% and 35.4% in upland soil.

Experiment 2: The long-term fertilization experiment on paddy soil was established in 1981, approximately 150 m away from the paddy soil experiment site. Before the experiment, the field had been used for rice (*Oryza sativa L.*) cultivation for over 100 years, and chemical fertilizers was not used. The crop system consists of early rice (April to July), late rice (July to November), and winter fallow from November to April of the next year. The paddy soil is classified as a typical stagnic anthrosols (IUSS, 2006). The parent material and its dominant mineral in paddy soil are the same as upland soil presents. The soil in the plough horizon (0–15 cm) before the experiment was as follows: pH (H_2O) 6.9, 27.96 g kg^{-1} SOM, 0.952 g kg^{-1} total N, 0.052 g kg^{-1} total P and 1.07 g kg^{-1} total K. The proportion of sand, silt and clay was 35.2%, 41.7% and 23.1% in paddy soil.

The two long-term fertilization experiment trials are composed of four treatments: (i) no fertilizer (Control), (ii) only nitrogen fertilizer (N), (iii) nitrogen, phosphate and potassium fertilizers (NPK), (iv) nitrogen, phosphate and potassium fertilizers plus manure (NPKM). The doses of chemical and organic fertilizers are different between upland and paddy experiments (Table 1).

In the upland soil, the experiment was a randomized complete block design with three replicates per treatment (plot size 22.2 m^2). The inorganic N, P, and K fertilizers used were urea, calcium superphosphate, and potassium chloride, respectively. All the P fertilizer and manure were applied as basal fertilizers before soil ploughing in each corn season, while half of the total N and K fertilizers were incorporated as basal fertilizers with the other half applied at the 10 leaf stage.

In the paddy soil, the design was same to upland soil, but the plot size was 46.67 m^2. Approximately 65% of the chemical N fertilizer (urea), 100% of the chemical P fertilizer (calcium-magnesium phosphate), 100% of the chemical K fertilizer (potassium chloride), and 100% of the organic manure were applied as basal fertilizers prior to rice seedling transplantating according to the treatment. The remaining N was applied in equal portions at the panicle initiation stage and 10 days before the flowering stage.

2.3. Grain yield and agronomic N use efficiency (ANUE)

Grain yields were determined by harvesting the whole area of each plot. The ANUE were calculated as follows:

$$\mathrm{ANUE} = \frac{\mathrm{Yield_T} - \mathrm{Yield_{Control}}}{\mathrm{N}}$$

where ANUE is agronomic N use efficiency (kg kg^{-1}); N is the amount of N fertilizer applied (kg ha^{-1}); $Yield_T$ is the yield (kg ha^{-1}) of either N, NPK, NPKM treatments; $Yield_{Control}$ is the yield (kg ha^{-1}) in Control treatment with no N, P and K fertilizer.

2.4. Soil sampling and analysis

Disturbed soil samples were taken by shovel from the plough horizon (0–20 cm) of upland and paddy soil in November 2014, after the late rice or late corn harvest. At each plot, five cores were randomly taken and mixed into one sample. In total, 24 soil samples were taken from two field experiments. Then, the homogenizing samples were divided into two parts; one part was air-dried at room temperature for measuring pH, soil organic matter (SOM), total N (TN), total P (TP),

Table 1
Fertilizer input of different treatments in red soil.

Treatments	Fertilizer input of every season/kg ha^{-1}							
	Upland soil				Paddy soil			
	N	P_2O_5	K_2O	Pig manure	N	P_2O_5	K_2O	Green or pig manure
Control								
N	60				90			
NPK	60	30	60		90	45	75	
NPKM	60	30	60	15,000	90	45	75	22,500

Note: The water content of pig manure was 70.8%, with containing 340 g kg^{-1} organic carbon, 12.0 g kg^{-1} N, 9.0 g kg^{-1} P and 10.0 g kg^{-1} K based on dry weight.
The water content of green manure (*Astragalus*) was 87.5%, with containing 403 g kg^{-1} organic carbon, 27.6 g kg^{-1} N, 2.00 g kg^{-1} P, 8.50 g kg^{-1} K based on dry weight.
In paddy soil, the green manure applied during the early rice season or pig manure applied during the late rice season.

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