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Partial substitution of chemical fertilizers with organic amendments increased rice yield by changing phosphorus fractions and improving phosphatase activities in fluvo-aquic soil

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Abstract
Purpose The aim of this study was to investigate the effect of combined use of chemical fertilizers with wheat straw and swine manure on rice yield and phosphorus (P) fractions distribution.
Materials and methods We selected two field experiments, both located in Hefei, Anhui province of China. We named these experimental sites as HF-1 and HF-2. The experiments HF-1 and HF-2 were initiated on 2013 and 2015 respectively in fluvo-aquic soil. Treatments included CK (no fertilizer), NPK (chemical fertilizers), NPKS (chemical fertilizers plus wheat straw), and NPKM (chemical fertilizers plus swine manure at HF-1, and chemical fertilizers plus fermented wheat straw at HF-2).
Results and discussion Results showed that NPKS and NPKM treatments increased grain yield, P use efficiency (PUE), P recovery efficiency, and partial factor productivity, and decreased apparent P balance compared with CK and NPK at both sites. NPKS and NPKM improved pH, organic matter, and nutrient contents in surface soil (0–20 cm) and also improved pH and organic matter content in sub-surface soil (20–40 cm), compared with CK and NPK treatments. Olsen P content in both soil depths was highest under NPKM, but NPKS had lower Olsen P content in sub-surface soil compared with that of NPK. Organic amendments changed P fractions and increased labile P and moderately labile P fractions, and decreased residual P compared with NPK. Organic amendments with chemical fertilizers also improved acid phosphomonoesterase and phosphodiesterase activities compared with chemical fertilization. In addition, path analysis showed relationship between soil properties and P mobility, and also explained soil properties influencing grain yield by changing PUE.
Conclusions Our results suggested that organic amendments improve crop yield through improving PUE by changing soil P fractions and increasing the phosphatase activities.

Keywords Olsen P · Phosphorus fractions · Phosphorus use efficiency · Rice yield · Structural equation modeling · Total P

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1 Introduction

Rice (*Oryza sativa L.*) crop is one of the most important crops in the world and the largest part of anthropogenic wetland on the earth is paddy soil, which is mainly cultivated for rice (Kögel-Knabner et al. 2010). However, rice production is largely limited by soil phosphorus (P) deficiencies in many parts of the world (Hedley et al. 1994; Fageria and Baligar 1997). In the fluvo-aquic soil (vertisol), the availability of P is very low, despite of regular fertilizer application specially in eastern China, due to soil P fixation with oxides and hydroxides of iron (Fe) and aluminum (Al) (Dubinsky et al. 2010; Igwe et al. 2010). Most of the farmers depend on chemical fertilizers to alleviate the soil P deficiency and to gain high crop yield. However, due to low P use efficiency (PUE) of

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