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Labile organic matter intensifies phosphorous mobilization in paddy soils by microbial iron (III) reduction

Imran Khan[a], Shah Fahad[b], Lei Wu[a,c], Wei Zhou[a], Peng Xu[a], Zheng Sun[a], Abdus Salam[a], Muhammad Imran[a], Mengdie Jiang[a], Yakov Kuzyakov[a,d,e,f], Ronggui Hu[a,*]

[a] *Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtse River), Ministry of Agriculture, College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, PR China*
[b] *Department of Agriculture, University of Swabi, Khyber Pakhtunkhwa, Pakistan*
[c] *Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences (CAAS), Beijing 100081, PR China*
[d] *Dept. of Soil Science of Temperate Ecosystems, Dept. of Agricultural Soil Science, University of Gottingen, 37077 Göttingen, Germany*
[e] *Institute of Environmental Sciences, Kazan Federal University, 420049 Kazan, Russia*
[f] *Agro-Technological Institute, RUDN University, 117198 Moscow, Russia*

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ABSTRACT

Iron (Fe) is one of the most abundant elements in the earth's crust and intensively interferes with the biogeochemical cycles of carbon (C) and phosphorous (P), especially in highly weathered tropical and subtropical soils. The strong affinity of phosphate to Fe oxides and hydroxides limits the P availability in paddy soils. Reductive dissolution of Fe(III) can release occluded and adsorbed P into solution and make it available for plant uptake. Such effects remain elusive, especially in highly weathered subtropical paddy soils with oscillating redox (Eh) conditions. Under submerged conditions, incomplete litter decomposition occurs and rice roots release large amounts of labile organic compounds as exudates. We investigated the role of acetate, formate, oxalate, and propionate on Fe(III) reduction, P mobilization, and CO_2 efflux in two paddy soils (i.e. oxisol and ultisol) of varying organic C (OC) and Fe(II) contents. Microbial mineralization of added labile C decreased soil Eh and increased the rates of Fe(III) reduction followed by P mobilization. This indicated that microbially-mediated Fe (III) reduction was intensified by labile OC compounds, which acted as energy sources and electron donors. The release of available P via Fe reduction was accompanied by peaks in Fe(II), dissolved OC, and pH and was followed by a decrease in iron-bound P (Fe—P). This implied that Fe—P was the main source of available P in the paddy soils. The faster release of available P in the oxisol than the ultisol indicated that the higher OC and Fe(II) contents in the oxisol allowed a fast Eh decrease, leading to rapid microbial oxygen (O_2) consumption and consequently faster and more intensive Fe(III) to Fe(II) reduction. This conclusion is supported by a faster Eh decrease in the oxisol than the ultisol corresponding to early P mobilization after input of labile C, and it suggests that Eh-driven Fe transformations and P mobilization are strongly modulated by labile OC mineralization.

1. Introduction

Paddy soils are subject to periodic changes in their oxic and anoxic environments, leading to fluctuating redox (Eh) conditions and a sequential reduction of terminal electron acceptors (TEAs) (Ratering and Schnell, 2000; Kögel-Knabner et al., 2010). This Eh and pH oscillation strongly governs the speciation, toxicity, bioavailability, and solubility of nutrients and metals in soil (Mansfeldt, 2004; Grybos et al., 2009). Decreased Eh under flooded conditions leads to modification of the microbial community and the sequential reduction of TEAs such as NO_3^-, Mn^{4+}, Fe^{3+}, and SO_4^{2-}, according to their energy release and availability (Unger et al., 2009). However, the onset of anaerobic conditions can reduce microbial utilization of chemically oxidized substrates and preferentially preserve more chemically reduced organic compounds in soils and sediments (Keiluweit et al., 2017). Most notably, in a fluctuating Eh environment, when oxygen (O_2) is depleted, Fe^{3+} in the iron (Fe) minerals quickly become favorite TEA and is reduced after nitrate (NO_3^-) consumption. Therefore, in tropical soils, a large proportion of phosphorous (P) bound Fe-minerals are susceptible to Eh and pH-induced transformations (Hall and Silver, 2015; Maranguit et al., 2017). Moreover, a large amount of the soil organic carbon (OC) that is stabilized via Fe and soil organic matter (OM)

* Corresponding author at: College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China.
E-mail address: rghu@mail.hzau.edu.cn (R. Hu).

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