Pedosphere **25**(3): 386–391, 2015
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Effects of Long-Term Groundwater Management and Straw Application on Aggregation of Paddy Soils in Subtropical China

YIN Li-Chu*, ZHANG Lei, YI Ya-Nan and LUO Lan-Fang

College of Resources and Environment, Hunan Agricultural University, Changsha 410128 (China)

(Received June 20, 2014; revised October 8, 2014)

ABSTRACT

Soil organic carbon (SOC) and iron (Fe)-oxides are important contributors of aggregate stability in highly weathered soils, and they are influenced by groundwater management and straw application. A 30-year plot experiment with early rice (*Oryza sativa* L.)-late rice-winter fallow rotations was conducted using a upland clay soil in cement pools under shallow groundwater table at a depth of 20 cm (SGT) and deep groundwater table at a depth of 80 cm (DGT) to simulate the groundwater tables of two types of important paddy soils, gleyed paddy soils and hydromorphic paddy soils, respectively, in subtropical China. Soil redox potential (Eh) was measured *in situ*, and 0–20 cm soil samples were collected for the analyses of soil Fe-oxides, SOC, and aggregates under SGT or DGT with different straw application treatments, in order to evaluate the interaction of groundwater management and straw application on paddy soil aggregation and the relative importance of SOC or Fe-oxides on soil aggregation. The results showed that soil Eh was restricted by irrigation, and its variation was more significant under DGT than under SGT. The decreased soil Eh or reduced drying and wetting cycles under SGT resulted in more SOC accumulation with the straw application, had no effect on soil free Fe-oxides (Fe_d), significantly increased the amorphous Fe-oxide (Fe_o) and complex Fe-oxide contents, but decreased the crystalline Fe-oxide content (Fe_d–Fe_o). The soils under DGT had more macroaggregates than those under SGT, but the difference decreased with the straw application. It could be concluded that soil Fe-oxides were the principal contributing factor to the aggregation of paddy soils in subtropical China and SOC was also an important contributing factor.

Key Words: groundwater table, Fe-oxides, long-term experiment, rice, soil organic carbon

Citation: Yin, L. C., Zhang, L., Yi, Y. N. and Luo, L. F. 2015. Effects of long-term groundwater management and straw application on aggregation of paddy soils in subtropical China. *Pedosphere*. **25**(3): 386–391.

Soil aggregation protects soil from erosion and enhances crop growth *via* increased aeration and better retention of water and nutrients (Lal and Shukla, 2004). In addition, soil aggregation slows mineralization of soil organic carbon (SOC) because it physically reduces microorganism access, enzymatic action, and oxygen diffusion (Lützow *et al.*, 2006). This also results in increased long-term carbon sequestration rates, which can serve as a sink for storage of excess atmospheric CO_2 (Six *et al.*, 2000a). The rate at which soil aggregates are re-formed and re-stabilized is influenced by many internal and external factors. The internal factors are linked to primary soil characteristics such as texture, clay mineralogy, SOC, and pH, whereas the external factors include climatic and biological variables and agronomic practices such as tillage, irrigation, and fertilization (Annabi *et al.*, 2011).

Soil organic carbon is usually considered the principal contributor of aggregate stability (Annabi *et al*, 2007; Abiven *et al.*, 2008; Ojeda *et al.*, 2008; Lashermes *et al.*, 2009). However, some studies have suggested that aggregation is less related to SOC in highly weathered soils, which are dominated by 1:1 clay minerals and ion (Fe) and Al-oxides that form aggregates *via* mineral-mineral interaction (Tisdall and Oades, 1982; Six *et al.*, 2000b; Denef *et al.*, 2002).

Paddy soils that are present in many areas of subtropical China are highly weathered and usually located in areas with variable groundwater table depths. Numerous studies have demonstrated the positive effects of increased SOC that occurs *via* input of organic matter on aggregation of paddy soils in subtropical China (Tong *et al.*, 2009; Huang *et al.*, 2010; Li *et al.*, 2010; Zhang *et al.*, 2012; Xia *et al.*, 2014). However, only a few studies have distinguished the effects of groundwater management on soil aggregation. Soils found in areas with shallow groundwater tables have a higher soil moisture content relative to deep groundwater areas and thus would increase SOC accumulation to improve soil aggregation (Yan *et al.*, 2013). However,

*Corresponding author. E-mail: lcyin0418@sohu.com.

this higher soil moisture content would also induce the activation of Fe-oxides, which would result in an opposing process to decrease soil aggregation. Therefore, the relative importance of SOC or Fe-oxides to soil aggregation under different groundwater management requires further examination.

In this study, a 30-year experiment in subtropical China was used to illuminate the interactions of groundwater management and straw application on aggregation of paddy soils. It was hypothesized that the SOC accumulation or activation of Fe-oxides under shallow groundwater table would be higher with the increased straw application, Fe-oxides would be more important to aggregate formation than SOC, and soil aggregation would decrease as the groundwater table depth increased due to the activation of Fe-oxides, even in the presence of increased SOC accumulation.

MATERIALS AND METHODS

Study site

This study was conducted at the experimental farm of Hunan Agricultural University in Changsha, Hunan Province, China (28°18′ N, 113°08′ E, 50 m above sea level). The mean annual temperature at the site is 17.2 °C, and the mean annual precipitation is 1 362 mm. The soil is an upland soil developed from Quaternary red clay, classified as an Oxisol according to USDA Soil Taxonomy (Soil Survey Staff, 2010). The 0–20 cm soil layer contained approximately 357 g kg^{-1} clay, 513 g kg^{-1} silt, and 130 g kg^{-1} sand and has a pH (H_2O) of 5.7, SOC content of 7.71 g kg^{-1}, free Fe-oxides (Fe_d) of 22.6 g kg^{-1}, amorphous Fe-oxides (Fe_o) of 1.1 g kg^{-1}, and crystalline Fe-oxides (Fe_d–Fe_o) of 21.5 g kg^{-1}.

Experiment

A long-term experiment with early rice (*Oryza sativa* L.)-late rice-winter fallow rotations, which are typical for subtropical China, was established in 1982 using a two-factor design and contained 36 experimental plots, with the groundwater table being the main factor and straw application being the second factor (Fig. 1). The experimental plots were constructed using a set of 1.6 m × 0.9 m × 1.5 m (length × width × depth) cement pools, into which the clay upland soil was placed according to its natural horizon. A shallow groundwater table (SGT) at a depth of 20 cm and a deep groundwater table (DGT) at a depth of 80 cm were included to simulate the groundwater tables of two types of important paddy soils in this area, gleyed paddy soils and hydromorphic paddy soils, respectively. The groundwater table depth of each plot was controlled by a 3-cm diameter stainless steel tube. The tube was placed at a depth of 20 or 80 cm under the surface soil and joined to a 1.5-m-deep cement water channel in which the water level was maintained at 20 or 80 cm underground (corresponding to the tube depth) throughout the year. Three straw application treatments were applied under each groundwater table level, including a treatment with only conventional N, P, and K fertilizers (urea, calcium superphosphate, and potassium chloride, respectively) (CF) and two treatments with rice straw application supplying 1/3 of the total fertilizer N (1/3OM) and 2/3 of the total fertilizer N (2/3OM). The replicates of every fertilization treatment differed at the beginning of the long-term experiment. There were 6, 12, and 6 replicates for the CF, 1/3OM, and 2/3OM treatments, respectively, under SGT. However, there were 3, 6, and 3 replicates for the CF, 1/3 OM, and 2/3 OM treatments, respectively, under DGT. For the CF treatment, fertilizer was applied at the rates of 150 kg N, 75 kg P_2O_5, and 150 kg K_2O per hectare in both the early and late rice seasons. Supplemental fertilizers were applied to the plots receiving rice straw to ensure uniformity of N, P, and

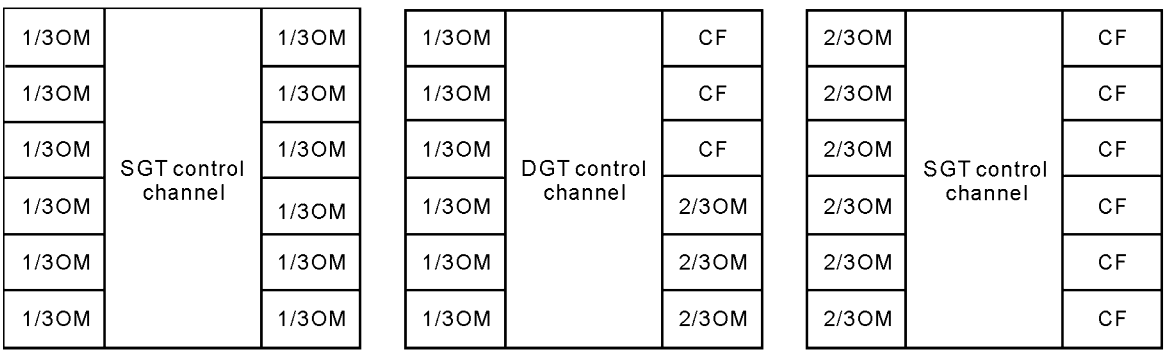

Fig. 1 Schematic illustration of the design of the long-term experiment with different groundwater tables and straw application treatments. SGT = shallow groundwater table at a depth of 20 cm; DGT = deep groundwater table at a depth of 80 cm; CF = no straw application with N, P, and K applied as urea, calcium superphosphate, and potassium chloride, respectively; 1/3OM = application of rice straw supplying 1/3 of the total fertilizer N; 2/3OM = application of rice straw supplying 2/3 of the total fertilizer N.