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Soil aggregate stability improves greatly in response to soil water dynamics under natural rains in long-term organic fertilization

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ABSTRACT

Soil structure in highly-weathered soils is adjusted by soil water content (SWC) under natural precipitation, and is also driven by the soil chemical properties. Such a relationship may be further dependent on types of fertilization. The objectives of this study were to investigate the effects of long-term fertilization (NPK, NPK + straw, manure, and control) after 17 continuous years on the SWC, temperature, aggregate stability, and the associated chemical properties (oxides, organic matter, and zeta potential), and to elucidate the relationship between SWC and aggregate. The aggregate stability (MWD), consecutive SWC, temperature, and chemical properties from 0 to 10 and 10 to 25 cm were measured during one year. Our results showed that the manure and NPK + straw treatments significantly improved the soil aggregate stability ($P < 0.05$) (e.g., average MWD 1.13 vs. 0.74 mm for manure vs. control at 0–10 cm) due to increase in the fraction of macroaggregate (> 2 mm). The SWC values and degree of variation at the same time were also improved more in manure and NPK + straw treatments than others. Soil aggregate MWD was significantly negatively correlated the SWC at the moment of soil sampling (WC_0) for all treatments. But the aggregates under two organic treatments was not significantly correlated with the antecedent SWC before half day and 4 days ($WC_{0.5}$ and WC_4), which indicated that the aggregates under manure and NPK + straw treatments were relatively stable when SWC changed before 0.5 and 4 days. The high stability of aggregates in the two organic-treated soils was also confirmed by very low relative slaking index values. The fertilization positive effect on soil aggregation to resist slaking was also attributed to the decline in soil clay zeta potential and improvement in soil OM and amorphous Fe oxides compared to control. The results suggest that long-term manure and NPK + straw application can improve aggregate stability and resistance to slaking under SWC variation whereas application of NPK only did not show such an effect.

1. Introduction

Ultisols cover approximately 1.14 million km^2 of Southeast China (Zhao et al., 2000), and worldwide Ultisols cover approximately 8% of the ice-free land surfaces in tropical and subtropical climate areas. Many Ultisols have relatively low organic matter contents which make them susceptible to nutrient loss (Lal, 2000; Zhang and Horn, 2001). These soils were also generally dominated by high proportion of microaggregates, which made them susceptible to water erosion (Yang et al., 2012). Besides, plants growing in red soils suffered from high root penetration resistance due to high bulk density, which, in turn, reduces the crop yield (He et al., 2017).

Research have shown that management practices (i.e. chemical amendment, organic fertilizers) can improve the aggregate structure of red soils, soil water retention, and reduce the bulk density (Munkholm et al., 2002; Perez-de-los-Reyes et al., 2011; Raboin et al., 2016; Cesarano et al., 2017), which therefore improve crop yield. The soil aggregate stability was controlled by the soil water retention, organic matter content, and soil oxides content (Algayer et al., 2014; Yin et al., 2016). Soil water was one of the major determinants of soil aggregate stability which included the current and antecedent (to the aggregate sampling time) soil water content (SWC), soil water dynamics, and the water wetting soil rate (in the aggregate stability analysis) (Amezketa, 1999; Algayer et al., 2014). The actual SWC in the field had high variation in the subtropical climate (Tao et al., 2017), which might influence aggregation development in different ways, however, this mechanism lacked investigation.

Soil water properties and aggregate stability were reported to be changed after fertilization. Different types of fertilization treatments resulted in different SWC especially at low suction (Nyamangara et al., 2001). The biochar and plant residues improved the soil water holding capacity and saturated hydraulic conductivity (Ma et al., 2016). A 6%

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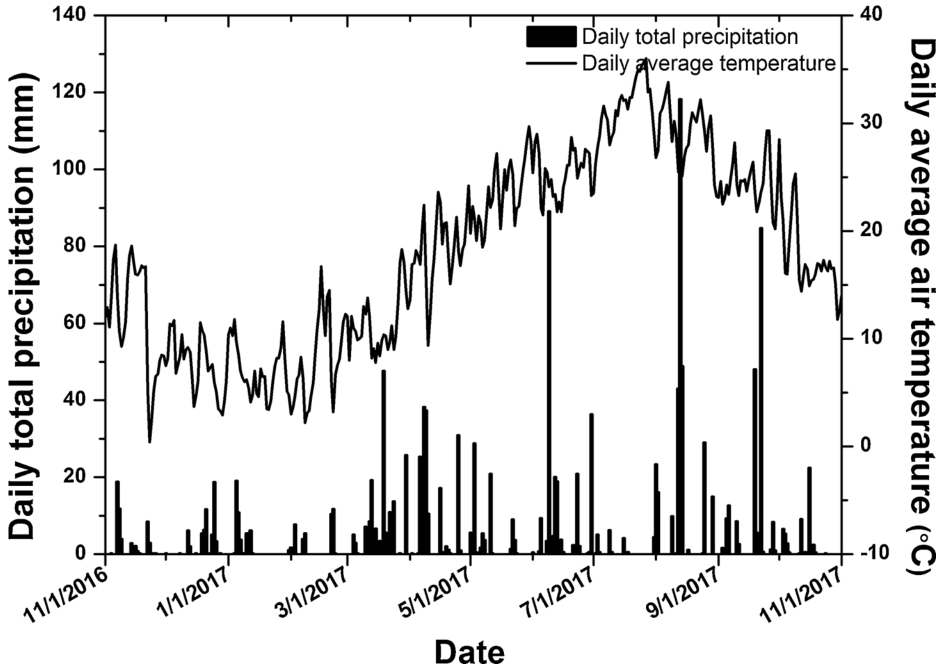

Fig. 1. Precipitation and air temperature during the study period.

increase in the SWC was observed in green-manure with N application compared to control at the stage of wheat stem appearance (Mosavi et al., 2009). But Jeffery et al. (2015) reported that biochar had no increase in soil water retention in a sandy soil probably due to no increase in the water stable aggregate. Soil water retention improvement was regulated by soil aggregation due to increase in organic matter after sugar foam ($CaCO_3$) application or due to chemical N, P, K fertilization (Perez-de-los-Reyes et al., 2011; Plaza-Bonilla et al., 2013). The SWC influence on aggregation after amendments was also attributed to its effect on the soil oxides reaction (important binding materials of aggregate). For example, Yin et al. (2016) reported that the macro-aggregate fraction in red soils increased positively with the accumulation of organic C and Fe-oxides by application of N + manure.

Relationships between the current SWC and aggregates have been addressed in the above studies (Munkholm et al., 2002; Mosavi et al., 2009), but few studies addressed the effect of hydric history on the aggregates. Ma et al. (2014) demonstrated that when the number of wetting-drying cycles increased in red soils in a laboratory, aggregate destruction was increased. In the field, Algayer et al. (2014) reported that the hydric history, especially the severe wetting-drying cycles in the Mediterranean climate, decreased the aggregate stability by slaking effect. But how intense wetting-drying cycle in their study affected the slaking effect was not investigated. The wetting-drying cycles may also influence the soil aggregation resistance to the slaking effect by changing the soil aggregate binding materials including soil organic matter and oxides content. Soil water dynamics was reported to accelerate the soil organic decomposition through inducing higher priming effect than the soils being at constant moisture with wheat straw addition (Liu et al., 2015). But wetting-drying cycle under rice straw addition did not increase the C mineralization in Sudano-Sahelian region in France (Yemadje et al., 2017). Soil water dynamics also influenced the aggregation through their effect on chemical reactions such as redox action (Maranguit et al., 2017) and zeta potential after amendments (Xu et al., 2012), with increase in the zeta potential resulting in increasing repulsion force between the adjacent soil particles (Marchuk et al., 2013).

However, few study investigated the soil aggregation change in red soils under long-term fertilization, and especially how aggregates responded to the soil water dynamics in the field was not clear. Therefore, we hypothesized that the application of chemical fertilizers and organic substances will improve the soil aggregates stability and change soil water dynamics. The objectives of this study were to investigate the effects of long-term fertilization (NPK, NPK + straw, manure, and control) after 17 continuous years on the SWC, temperature, aggregate stability, and the associated chemical properties (oxides, organic matter, and zeta potential), and to elucidate the relationship between SWC and aggregate.

2. Materials and methods

2.1. Study site description and research design

This study was conducted at an experimental station (30°01′N, 114°21′E) affiliated to the Huazhong Agricultural University in southeast Hubei, China. The local area had an annual mean temperature of about 16.8 °C and annual mean precipitation of about 1300 mm with most of the precipitation occurring from April to July. Different types of fertilizer treatments were applied annually into the research plots (each plot is 7 m × 3 m) in the station from 1998 to 2015, in a total of 17 years. The research design was a completely randomized block design with four treatments and three replicates, for a total of 12 plots. The different treatments included (1) the inorganic fertilizers (NPK) (N: 175 kg ha^{-1} as $CO(NH_2)_2$; P: 150 kg ha^{-1} as $Ca(H_2PO_4)_2{\cdot}2H_2O$; K: 115 kg ha^{-1} as K_2O), (2) NPK mixed with rice straw (NPK + straw) (NPK + 1666 kg ha^{-1} rice straw), (3) chicken manure (Manure) (10,000 kg ha^{-1}), and (4) control (without any fertilizers). The NPK application rate was similar as local level, but the other two treatments application rates were higher than the "common criteria" (5000 kg ha^{-1}) to satisfy the needs of corn in the study site (Tan et al., 2006). The plots planted summer corn (*Zea mays* L.) before the year of 2015. Meteorological data were recorded by a climate station in a 20 m distance to the research plots as shown in Fig. 1.

In the study site, the red soils (Albaqult) are developed from Quaternary red clay, and are classified as Ultisols using the USDA Soil Taxonomy system. The red soil has a thin A horizon and very thick B horizon through the field investigation. Disturbed soil samples were collected from 0 to 10 and 10–25 cm in each treatment for basic soil properties analysis which included the soil texture, bulk density,