Catena 137 (2016) 545–553

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Estimating the influence of related soil properties on macro- and micro-aggregate stability in ultisols of south-central China

Jun-guang Wang [a], Wei Yang [b], Bing Yu [a], Zhao-xia Li [a], Chong-fa Cai [a,*], Ren-ming Ma [a]

[a] Key Laboratory of Arable Land Conservation (Middle and Lower Reaches of Yangtze River) of the Ministry of Agriculture, Soil and Water Conservation Research Centre, Huazhong Agricultural University, Wuhan 430070, People's Republic of China

[b] Hubei Water Resources Research Institute, Wuhan 430070, People's Republic of China

ARTICLE INFO

Article history:
Received 31 March 2015
Received in revised form 3 November 2015
Accepted 4 November 2015
Available online 11 November 2015

Keywords:
Macro- and micro-aggregates
Stability
Soil properties
Ultisols

ABSTRACT

Background: Stable macro- or micro-aggregates are important for preventing soil degradation. The interactions among soil aggregates and stabilizing agents—like clay, soil organic matter (SOM), Fe, and Al oxides—are complex and have not been fully understood.

Methods: Eight ultisol samples were collected from the surface (0–10 cm) and subsurface layers (10–20 cm). The macro-aggregate stability was determined by wet sieving, and the micro-aggregate distribution was determined via particle size distribution analysis; however, no chemical dispersant (sodium hydroxide) was applied. Using the PLSR models, the main soil properties that affect macro-aggregate and micro-aggregate stability were estimated.

Results: All soils were strongly acidic (pH 4.28–5.56) with low SOM content (<20 g kg^{-1}). The dithionite-citrate-bicarbonate extractable Fe_d and Al_d were the dominant forms in Fe and Al oxides, much greater than acid ammonium oxalate extractable Fe_o and Al_o. For most soils, the percentage of >5 mm aggregates was the highest, and the percentage of 2–1 mm aggregates was the lowest after wet sieving. Soil parent materials had a significant effect on the particle size distribution of the micro-aggregates. The stability of macro-aggregates and micro-aggregates from Quaternary red clay was stronger than that from Shale ($p < 0.05$). Regardless of the soil parent materials, the water stability of surface cropland soil macro-aggregates was significantly lower than that of the other land-use types, but the micro-aggregate stability exhibited no trend across different land use types.

Conclusion: Al_d was the most important binding agent of the macro-aggregates, and clay was the main binding agent of the micro-aggregates, followed by the Fe_d, Al_o, CEC and SOM, while Fe_o was the weakest agent.

1. Introduction

The stability of soil aggregates can affect water movement and storage in soils, and it can also influence soil aeration, erosion, and biological activities as well as crop growth. High and sustainable soil aggregate stability is thus an important characteristic for preserving soil productivity and restraining soil erosion and degradation (Amézketa, 1999). Macro-aggregate stability is often considered as a key index in studies of soil erodibility or soil degradation (Barthès and Roose, 2002; Cammeraat and Imeson, 1998; Idowu, 2003; Yan et al., 2008), and micro-aggregate stability is also used to estimate or predict soil erosion and surface runoff (Darboux and Le Bissonnais, 2007). The weak water stability of micro-aggregates has become a major cause of increasing water erosion on agricultural lands in some areas of Africa (Opara, 2009).

The stability of soil macro- and micro-aggregates can be affected by dozens of different soil intrinsic factors and depends on soil formation processes, biological factors, agricultural management and climate (Amézketa, 1999). Improving our understanding of these processes is fundamental in order to take action to maintain macro- and micro-aggregate stability in soils. Some researchers have found that soil intrinsic factors—such as the content of clay, organic matter, and oxides—contributed to the cohesive strength of aggregates through binding processes in their selected soils (Levy and Mamedov, 2002; Wuddivira et al., 2006). Soil organic matter is a crucial component for aggregate formation and stabilization (Boix-Fayos et al., 2001; Six et al., 2004; Noellemeyer et al., 2008), and is positively correlated with macro-aggregate distribution (Green et al., 2005; De Gryze et al., 2008; Huang et al., 2010). Boix-Fayos et al. (2001) observed that the macro-aggregate stability depends on the organic matter content when this was greater than 5–6%, and Huang et al. (2010) showed that the percentages of >0.25 mm water-stable aggregates correlated well with the organic matter contents of eroded ultisols. However,

* Corresponding author at: College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, People's Republic of China.

E-mail addresses: jgwang@mail.hzau.edu.cn (J. Wang), yw.hbwri@gmail.com (W. Yang), yu20008bing@webmail.hzau.edu.cn (B. Yu), zxli@mail.hzau.edu.cn (Z. Li), cfcaihzau@163.com, cfcai@mail.hzau.edu.cn (C. Cai), marenming521@163.com (R. Ma).

http://dx.doi.org/10.1016/j.catena.2015.11.001
0341-8162/

some researchers have shown that soils with higher contents of Fe and Al oxides tend to have more stability for macro- and micro-aggregates (Goldberg et al., 1990; Pinheiro-Dick and Schwertmann, 1996). Igwe et al. (1995, 2009) and Li et al. (2005) showed that in some Inceptisols and ultisols the low organic-matter content did not affect the formation and stabilization of aggregates. They claimed that sesquioxides were ultimately responsible for aggregate formation and stabilization, and their contributions to aggregate formation could vary greatly. There has since been discussion as to which particular element in the sesquioxide group was responsible for aggregate formation. Among sesquioxides, Al was found to be more effective than Fe as an aggregating agent (Keren and Singer, 1990; Mbagwu and Schwertmann, 2006). However, Arca and Weed (1966) indicated that aggregation in oxide-rich soils was more strongly correlated with free Fe oxide content than other soil properties. Other researchers identified oxalate-extracted oxides (Fe, Al) as heavily involved in aggregate formation in some Oxisols, Inceptisols, and Andisols from Brazil, Cameroon, and Chile (Pinheiro-Dick and Schwertmann, 1996; Huygens et al., 2005).

Ultisols (more commonly known as “red soils”) cover approximately 1.14 million km^2 in southeastern China and are the dominant soil type in South American and Southeastern Asia. Improper land use and soil management, undulating topography, and poor soil properties may have caused severe soil erosion in ultisols areas, which has become one of the most challenging environmental problems in China (Zhao et al., 2000; Zhang et al., 2004). Aggregate water stability is clearly an important characteristic affecting soil erosion (Yan et al., 2008; Wang et al., 2012). Although a number of studies have examined the relationship between chemical properties and macro-aggregate stability in ultisols from subtropical regions, the results have been inconclusive (Huang et al., 2010; Li et al., 2005; Zhang and Horn, 2001). Some studies have indicated that micro-aggregate stability in some ultisols and inceptisols from southeastern Nigeria are affected by iron and aluminum oxides or different land use types (Igwe et al., 2009; Opara, 2009). However, little information exists on the micro-aggregate size distribution and stability in subtropical soils and compares this with the research on macro-aggregates. This study aims to (1) identify the size distribution and stability of the soil macro- and micro-aggregates from subtropical China, (2) estimate the influence of related soil physical and chemical properties on macro- and micro-aggregate stability, and (3) evaluate their roles in the structural stability of these soils.

2. Materials and methods

2.1. Soils

Soil samples were collected from Xianning City, Hubei Province in the south-central part of China (Fig. 1.). The sampling sites were in the subtropical zone, which has an annual rainfall of 1572 mm and annual average temperatures of 16.8 °C. The elevation of this area is 32–52 m above sea level. These areas are hilly with different degrees of erosion. Soil erosion in some areas of the ultisol region reaches 7000 t km^{-2} per year (He and Sun, 2008). Eight soil samples were collected from the surface layer (0–10 cm) and eight from a subsurface layer (10–20 cm). Each sampled area was about 0.1 to 0.3 ha. This number of samples is representative for the study area. The eight sample sites were geographically representative for the soils in Hubei Province. They covered the most soil parent materials in subtropical China. Considering the soil parent materials and different land use, we selected the eight soil samples derived from Quaternary red clay and Shale from Xianning City. General characteristics of these sampling sites are shown in Table 1.

2.2. Laboratory methods

The wet sieving method of Yoder (1936) was modified to measure macro-aggregate stability. Air-dried soil samples were sieved by hand using a column of five sieves at sizes of 5.00, 2.00, 1.00, 0.50 and 0.25 mm. The percentages of different aggregates in the bulk soil as determined with the dry-sieving method were calculated and recorded. Based on these percentages, soil samples of different aggregate sizes were prepared. Approximately 50 g of composed soil samples was placed on the first sieve of a sequential nest and gently moistened to avoid sudden rupture of the aggregates. The sample was then sieved in distilled water at 30 oscillations per minute (along 4 cm amplitude) for 30 min. The resistant soil materials on each sieve were transferred into clean beakers. These soil materials were then oven-dried gently at 40 °C for 48 h and weighed. Macro-aggregate stability was expressed by the content of water-stable aggregates that were greater than 0.25 mm ($WSA_{>0.25}$), mean weight diameter (MWD), and the aggregate deterioration rate (ADR) by wet sieving. Equations used in this research include:

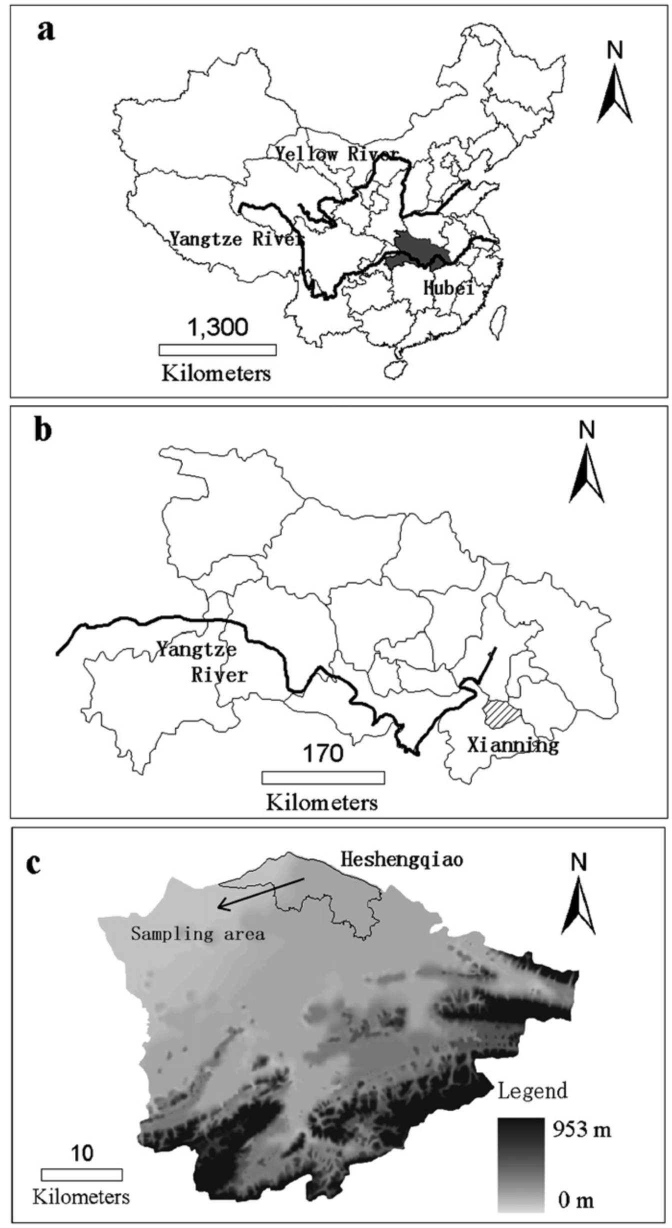

Fig. 1. Location of the study area and sampling sites: (a) location of Hubei Province in China, (b) location of Xianning County in Hubei Province, (c) location of Heshengqiao town in Xianning County.

$$MWD = \sum_{i=1}^{7} x_i w_i$$