



Spatial variations of aggregate stability in relation to sesquioxides for zonal soils, South-central China



Xinliang Wu, Chongfa Cai, Janguang Wang*, Yujie Wei, Shuo Wang

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, China

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ABSTRACT

Soil aggregate stability is an important soil property affecting soil functions and erosion. However, there exists some divergence on the relationship between different forms of sesquioxides and aggregate stability, and limited knowledge is available about spatial evolution of aggregate stability under climate conditions (temperature and precipitation) and anthropogenic activities. In this study, the spatial variation and profile distribution of soil aggregate stability and its relation to sesquioxides under cultivation in different zonal soils were investigated. Typical zonal soils in different weathering degrees were selected that were exposed to an increasing trend of annual average temperature and precipitation (from central to south China). These soils contained low organic matter (<3%) and high variation of sesquioxides in different forms (coefficient of variations CVs in 34–104%). Soil free oxides (Fe_d and Al_d) contents showed an increasing trend across the zonal soils with the content of Fe_d higher than that of Al_d . Both amorphous oxides (Fe_o and Al_o) and complex oxides (Fe_p and Al_p) did not present the obvious increasing variation unlike free oxides across the zonal soils. Soil Al_p content was higher than Fe_p content and their complex degrees decreased with soil depth due to complexation with soil organic matter. Soil aggregate stability showed a distinct unimodal trend across the zonal soils and water aggregate stability decreased with soil depth. In general, slaking was the main disruptive force in disaggregation, followed by mechanical breakdown. Multiple stepwise regression analysis showed that complex oxides especially the Al_p were strongly related with aggregate stability, synthetically contributing to dry aggregate stability logarithmically and to water stability in a power function. Soil organic matter had a negative effect on dry aggregate stability. Interestingly, it was found that non-complex Fe oxides in amorphous oxides (Fe_o – Fe_p) improved water aggregate stability against slaking. More studies are needed to gain more insights into the interaction between soil aggregate stabilization and sesquioxides in future.

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1. Introduction

Soil erosion has been a global environmental problem, leading to the degradation of cultivated farmlands. Factors such as soil properties, rainfall characteristics, topographic conditions, vegetation cover, and land use and their interactions influence soil erosion (Dlamini et al., 2011). Aggregate stability is an important soil property that affects the soil functions (e.g., movement and

storage of water, aeration, tillage, carbon sequestration, and erodibility), and has been an indicator of soil quality and soil susceptibility to runoff and erosion (e.g., Le Bissonnais, 1996; Six et al., 2004; Chaplot et al., 2007; Deviren Saygin et al., 2012; Chaplot and Cooper, 2015). For the importance of aggregate stability, a large number of researches have been conducted to understand the formation and stability of soil aggregates (Six et al., 2004; Bronick and Lal, 2005).

Aggregate stability is affected by both soil intrinsic properties (e.g. clay type and content, organic matter and sesquioxides) and external factors (e.g. climate, soil formation processes, agricultural management) (Bronick and Lal, 2005). The sesquioxides and organic matter in tropical and subtropical soils are widely regarded as the main inorganic and organic binding agents for soil aggregation and stabilization (Pinheiro-Dick and Schwertmann,

* Corresponding author at: College of Resources and Environment, Huazhong Agricultural University, Wuhan 430070, China. Fax: +86 27 87288249.

E-mail addresses: wuxinlianghzau@163.com (X. Wu), cfcail@mail.hzau.edu.cn (C. Cai), jgawang@mail.hzau.edu.cn (J. Wang), weyujay@gmail.com (Y. Wei), 782893258@qq.com (S. Wang).

1996; Igwe et al., 1999, 2009; Zhang and Horn, 2001; Six et al., 2004; Barthès et al., 2008). Researches (Tisdall and Oades, 1982; Oades and Waters, 1991) have indicated that it is hydrous oxides of iron and aluminum rather than organic matter, cementing particles together in water-stable aggregates (>100 μm), especially in soils that contain more than 10% sesquioxides. Pinheiro-Dick and Schwertmann (1996) found that the oxalate-extracted oxides were mainly responsible for the formation of aggregates in some Oxisols and Inceptisols from Brazil and Cameroon. The effect of free Fe and Al oxides (Fe_d and Al_d) in soil aggregation may be more important in soils with low organic matter (Six et al., 2002). Oxalate- and pyrophosphate- extractable Fe (represented as Fe_o and Fe_p) and to some extent total Al (Al_t) can act as aggregating agents among the different forms of oxides (Igwe et al., 2009).

However, there exists some divergence on the specific role of different forms of sesquioxides in aggregation and stabilization of soil structure. For instance, Duiker et al. (2003) demonstrated that the Fe_o component is more effective than Fe_d in stabilizing soil aggregates. Mbagwu and Schwertmann (2006) indicated that Al oxides were a more important agent in aggregation of gibbsite than iron oxides. Barthès et al. (2008) reported that Al-containing sesquioxides had a more important aggregating role than soil organic matter (SOM) in tropical soils. The discrepancy for these variable effects of Fe and Al (hydr) oxides on aggregation may be related to either (i) the differences between Fe and Al (hydr) oxides not determined in their studies, or (ii) other soil characteristics that influence the aggregating capacity of Fe and Al (hydr) oxides (Barthès et al., 2008).

Soil structural development and aggregation occur within the context of natural pedogenic processes and anthropogenic activities (Bronick and Lal, 2005). Climate conditions and human activities influence translocation of materials in soil profiles through leaching, bioturbation, eluviations, and illuviation. In these processes, the interaction of Al^{3+} and Fe^{3+} with clay or SOM can synergistically promote aggregation (Six et al., 2000) and improve aggregate stability (Barral et al., 1998; Molina et al., 2001). Polyvalent Al^{3+} and Fe^{3+} cations improve soil structure through cationic bridging and formation of organo-metallic compounds (Amézqueta, 1999). There exist various forms of sesquioxides, such as non-free oxides, crystalline oxides, amorphous oxides (complex and non-complex oxides). However, detailed knowledge is lacking about the effect of specific forms of sesquioxides on the aggregate stability.

The formation and stability of soil aggregates can be affected by dozens of different factors (Jozefaciuk and Czachor, 2014; Peng et al., 2015). For better investigating the relationship between aggregate stability and sesquioxides, we selected seven typical zonal soils in different weathering degrees and under cultivation with low organic matter (<3%) and high variation of sesquioxides (coefficient of variations CV 37–104%) on the similar parent materials. The objectives of this study were to: (i) study the content and morphologic variation of Fe and Al oxides by chemical

selective extraction techniques; (ii) investigate the spatial variation of soil aggregate stability; and (iii) identify the relationship between aggregate stability and the forms of Fe and Al oxides under cultivation in different zonal soils.

2. Materials and methods

2.1. Study sites and soil sampling

Seven typical zonal soils were selected from central and south China along a climatic transect including three monsoon climatic regions (temperate, subtropical and tropical monsoon climate). Mean annual temperature and precipitation range from 14 °C to 24 °C and from 640 mm to 1778 mm, indicating an increasing trend for heat and water conditions contributing to the soil weathering (i.e. desilicification and ferrallitization). The sampling sites are separately located in Zhengzhou city (ZZ) in Henan province, Xiangyang city (XN), Jingshan county (JS), Xianning city (XN) in Hubei province, Changsha city (CS) in Hunan province, Shaoguan city (SG) in Guangdong province, and Wenchang city (WC) in Hainan province. These soils were classified as Lixisols (ZZ), Alisols (XY and JS) and Acrisols for other soils (IUSS Working Group WRB, 2014). Except ZZ from alluvium and WC from neritic deposit, other soils were derived from quaternary clay. All sampling sites were located on gentle slopes or plain with a slope gradient smaller than 5%, and cultivated by human beings with intact genetic soil profile in slight erosion. Detailed information of soil sampling sites including location, climate, parent material, farming system, topography and soil profile is listed in Table 1 and Fig. 1.

At each site, a soil profile pit was dug, and soil samples were taken from three distinct profile horizons, that is, eluvium (A), illuvium (B) and parent material horizon (C) from July to September in 2012. Undisturbed soil cores (100 cm^3) were taken for the analysis of bulk density. After collection, the field-moist disturbed soil samples were gently broken up by hand so that the large clods broke along natural fissures, and then fully air-dried and ground through different size sieves for physical and chemical analysis after removing large roots and other fresh organic materials.

2.2. Soil analysis

Soil basic properties were determined by standard analytical methods: bulk density (BD) was determined on undisturbed soil cores by the oven-dried weight; pH was measured potentiometrically at 1:2.5 soil/water ratio in mass; soil organic matter (SOM) by acid potassium-dichromate ($\text{K}_2\text{Cr}_2\text{O}_7$, $c = 0.4 \text{ M}$) digestion (Walkley and Black, 1934); cation exchange capacity (CEC) by ammonium acetate exchange method (Thomas, 1982); soil texture by wet sieving-pipette method after dispersion in 0.5 M sodium hydroxide or sodium oxalate solutions (Gee and Bauder, 1986); clay mineralogy by powder X-ray diffraction (XRD) on a Bruker

Table 1
Main characteristics of soil sampling sites.

Code	Longitude/latitude	MAT/°C	MAP/mm	Topography	Land use	Parent material	WRB soil group(2014)
ZZ	113°32'E/34°54'N	14.2	640.9	Plain	Maize/wheat	Alluvium	Lixisols
XY	112°09'E/32°19'N	16.0	878.3	Terrance	Maize	Quaternary clay	Alisols
JS	113°14'E/30°57'N	16.3	1179.0	Terrance	Soybean	Quaternary clay	Alisols
XN	114°22'E/30°00'N	16.8	1577.4	Terrance	Tea plantations	Quaternary clay	Acrisols
CS	112°46'E/28°22'N	17.0	1422.4	Terrance	Waste land	Quaternary clay	Acrisols
SG	113°56'E/24°18'N	20.4	1778.0	Terrance	Potato	Quaternary clay	Acrisols
WC	110°41'E/19°39'N	23.9	1721.6	Terrance	Rubber plantation	Neritic deposit	Acrisols

MAT, mean annual temperature; MAP, mean annual precipitation. WRB refers to the World Reference Base for soil resources 2014.

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