Soil & Tillage Research 180 (2018) 232–237

Contents lists available at ScienceDirect

Soil & Tillage Research

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

# Long-term animal manure application promoted biological binding agents but not soil aggregation in a Vertisol

Z.C. Guo[a,b], Z.B. Zhang[a], H. Zhou[a], M.T. Rahman[a,b], D.Z. Wang[c], X.S. Guo[c], L.J. Li[c], X.H. Peng[a,*]

[a] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, 210008, PR China
[b] University of Chinese Academy of Sciences, Beijing, 100081, PR China
[c] Institute of Soil and Fertilizer Research, Anhui Academy of Agricultural Science, Hefei, 230031, PR China

ARTICLE INFO

*Keywords:*
Long-term fertilization
Soil structure
Aggregate stability
Organic manure
Soil organic carbon

ABSTRACT

To improve soil aggregation through proper fertilization is very important for enhancing soil quality and crop productivity. However, the response of soil aggregation varies with the fertilization practices. The objective of this study was to determine the effects of long-term application of inorganic fertilizer, straw and manure on water-stable aggregate distribution ($> 2$ mm, 0.25–2.0 mm, 0.053–0.25 mm, and $< 0.053$ mm), soil organic carbon (SOC), glomalin-related soil proteins (GRSP) and microbial biomass carbon (MBC) as the major biological binding agents in a Vertisol. The fertilization experiment established in 1982 is composed of six treatments as follows: no fertilization (Control), balanced inorganic fertilizer (NPK), low and high amount of straw plus inorganic fertilizer (NPKLS and NPKHS), and animal manure (both pig and cattle) plus inorganic fertilizer (NPKPM and NPKCM). Long-term straw and manure fertilization significantly increased SOC, GRSP and MBC ($P < 0.05$), while the application of the two animal manures also increased dispersing agents like exchangeable $Na^+$. Consequently, the straw incorporation promoted the formation of $> 2$ mm macroaggregates significantly ($P < 0.05$) but the two animal manures did not ($P > 0.05$). The SOC, GRSP and MBC played an important role in the formation and stabilization of 0.25–2.0 mm aggregates. Our results indicate that animal manure may degrade soil structure due to the high salt content but straw incorporation is a judicious practice for sustainable agriculture in the Vertisol.

## 1. Introduction

Inappropriate and overuse fertilizations have increased the risk of soil degradation, aggravating the susceptibility of cropland soils to decline of soil structure, acidification, loss in soil biodiversity and even disruption in ecosystem functions (Bronick and Lal, 2005; Lal, 2015). On the other hand, a judicious fertilization practice can restore degraded soils, i.e., enhancing SOC, improving soil structure, and increasing agronomy performance (Bronick and Lal, 2005; Lal, 2015; Luna et al., 2016; Mikha et al., 2015). Traditionally, animal manure is regarded as an excellent organic fertilizer which is commonly recommended to apply together with inorganic fertilizers. In practice, to keep a nutritionally balanced diet and obtain higher productivity, slats supplementation is widely added in forage that animals (commercial livestock or poultry) have a much greater appetite (Johansson, 2008). Application animal manure with high salt content into soil may stress crop growth and degrade soil structure (Yao et al., 2007). This detrimental effect of animal manure is generally ignored.

As soil structure provides pathways for the transport of water, nutrients and gases, and habitats for microorganisms, it is a fundamental property of soil fertility and quality (Peng et al., 2015). Aggregate stability is universally recognized as an indicator of soil structure (Amézketa, 1999). Most importantly, stable soil aggregates can play a key role in physical protection of SOC and sustain crop production (Lu et al., 2014; Luna et al., 2016). Therefore, to promote and maintain larger stable aggregates is crucial for the sustainable agriculture. Although the effects of long-term fertilization on soil aggregation have well been documented in previous studies (Bronick and Lal, 2005; Haynes and Naidu, 1998), there is still no consensus on their effects. Some studies reported that the long-term application of inorganic fertilizer improved the soil aggregate stability in comparison to non-fertilization (Das et al., 2014; Hati et al., 2008; Tripathi et al., 2014). Other studies showed that the inorganic fertilization did not change or even decreased the aggregate stability, although it increased the SOC level (Bandyopadhyay et al., 2010; Celik et al., 2010; Xie et al., 2015; Xin et al., 2016; Yan et al., 2013; Zhang et al., 2016; Zhou et al., 2017). The reduction of soil aggregation may be associated with the contents of binding and dispersing agents. The incorporation of straw to

---

[*] Corresponding author.
*E-mail address:* xhpeng@issas.ac.cn (X.H. Peng).

https://doi.org/10.1016/j.still.2018.03.007
Received 9 November 2017; Received in revised form 4 March 2018; Accepted 5 March 2018

soil was widely observed to promote the soil aggregate stability (Das et al., 2014; Zhang et al., 2017, 2014a). In the contrast, manure application was reported to improve soil aggregation in some studies (Bandyopadhyay et al., 2010; Celik et al., 2010; Das et al., 2014; Hati et al., 2008; Mikha et al., 2015; Tripathi et al., 2014; Yan et al., 2013), whereas no or even negative effect was observed in other works (Domingo-Olivé et al., 2016; Dou et al., 2016; Xie et al., 2015; Xin et al., 2016; Zhang et al., 2016). Obviously, the response of soil aggregation to fertilization practice may vary with the type of the applied fertilizer and soil properties. Indeed, the negative effect of fertilization on soil aggregation has not been understood in-depth, mainly because it is offset by increasing SOC level. Thus, it is worthy assessing the comprehensive effect of the fertilization practice on soil aggregation.

The improvement of soil aggregation after the incorporation of organic amendments (i.e., straw, compost and manure) depends largely on the associated binding agents (Xie et al., 2015; Zhang et al., 2016; Zhang et al., 2014b). SOC, GRSP and MBC are widely recognized as three main biological binding agents associated with soil aggregation (Six et al., 2004), but their abundance and characteristics may be related with the quality and quantity of organic amendments (Abiven et al., 2009). A great number of studies have reported a good relationship between the soil aggregate stability and associated binding agents (Su et al., 2006; Zhang et al., 2012; Zhang et al., 2014b), but no relation was also observed in some cases (Rillig, 2004; Xie et al., 2015; Zhang et al., 2016). Generally, easily glomalin-related soil protein ($GRSP_e$) was highly correlated with soil aggregate stability than total glomalin-related soil protein ($GRSP_t$) (Zhang et al., 2012; Zhang et al., 2014b). Clearly, the associated binding agents perform differently in the soil aggregate formation and stabilization.

Poor soil structure is a serious problem of Vertisol which makes it difficult for agricultural workability and crop growth. Thus, improving soil structure is mandatory as it mediates a range of soil biological and physical processes. In order to better understand the mechanisms of soil aggregation of Vertisol, we investigated a typical Vertisol, located in the Huang-Huai-Hai plain, one of main wheat production bases in China. Our objective was to determine the effects of continuous 34-year long-term applications of inorganic fertilizer, straw and animal manure on soil aggregation and biological binding agents. We hypothesized that the fertilization could promote soil aggregation via increasing SOC and other biological binding agents.

## 2. Materials and methods

### 2.1. The soil

The soil was sampled from a long-term fertilization experiment established in 1982, at the Madian Agro-Ecological Station in Mengcheng county, Anhui province, China (33°13′N, 116°37′E). The site is characterized by a sub-humid warm temperate continental monsoon climate where the mean annual temperature is 16.5 °C and the mean annual precipitation 900 mm. The soil, classified as a Vertisol according to the USDA soil taxonomy (Soil Survey Staff, 2010), has been locally known as Shajiang black soil. This soil is developed from fluvio-lacustrine sediments and mainly distributed in Huang-Huai-Hai Plain with about 4.3 million hectares. Prior to the experiment establishment, the initial soil properties of plough horizon (0–20 cm) were as follows: bulk density 1.45 g $cm^{-3}$; clay (< 0.002 mm) 414 g $kg^{-1}$, silt (0.002–0.02 mm) 306 g $kg^{-1}$; pH 7.4 (soil:water ratio of 1:2.5); SOC 5.8 g $kg^{-1}$; total N 0.96 g $kg^{-1}$; total P 0.28 g $kg^{-1}$; alkali-hydrolysable N 84.5 mg $kg^{-1}$; available P 9.8 mg $kg^{-1}$; available K 125 mg $kg^{-1}$.

### 2.2. Experimental design and treatments

This long-term fertilization experiment included six treatments with a wheat-soybean cropping system (Table 1): (1) no fertilization (Control); (2) balanced inorganic fertilizer (NPK); (3) balanced inorganic fertilizer plus a low amount of wheat straw (NPKLS); (4) balanced inorganic fertilizer plus a high amount of wheat straw (NPKHS); (5) balanced inorganic fertilizer plus pig manure (NPKPM); (6) balanced inorganic fertilizer plus cattle manure (NPKCM). Each treatment has 4 replicates and each plot was 15 m × 5 m in size. The amounts of inorganic fertilizer N, $P_2O_5$ and $K_2O$ are 180, 90, 135 kg $ha^{-1}$, respectively. The low and high amounts of wheat straw incorporated are 3 750 and 7 500 kg $ha^{-1}$, respectively. The amount of pig manure is 15 Mg $ha^{-1}$ and cattle manure is 30 Mg $ha^{-1}$. The amounts of straw, pig manure and cattle manure are based on fresh weight. Organic and inorganic fertilizers are applied to each plot before the wheat planting in autumn, while no fertilization is applied in soybean season. On average, the C, N, P and K contents of dry base were 482, 5.5, 1.2, and 11.5 g $kg^{-1}$ for wheat straw; 366, 17, 9.0, and 9.0 g $kg^{-1}$ for pig manure; 374, 8.0, 4.0, and 4.0 g $kg^{-1}$ for cattle manure, respectively. The N, P, and K fertilizers used are urea, superphosphate and potassium chloride, respectively. Tillage management (e.g., rotary tillage) is the same among the treatments. Soil samples of each plot were taken from five different points at 0–20 cm soil depth using a soil auger after soybean harvest in October 2016. Subsequently, the moist soil samples passed through an 8 mm sieve, air dried and stored at room temperature after removing stones and crop debris.

**Table 1**
Application rates of inorganic and organic fertilization in the Vertisol (kg $ha^{-1}$ $yr^{-1}$).

| Treatments | Chemical fertilizer | | | Organic amendments | | Input of crop residue derived C[a] |
|---|---|---|---|---|---|---|
| | N | $P_2O_5$ | $K_2O$ | Straw | manure | |
| Control | 0 | 0 | 0 | 0 | 0 | 160 |
| NPK | 180 | 90 | 135 | 0 | 0 | 1 930 |
| NPKLS | 180 | 90 | 135 | 3 750 | 0 | 2 100 |
| NPKHS | 180 | 90 | 135 | 7 500 | 0 | 2 170 |
| NPKPM | 180 | 90 | 135 | 0 | 15 000 | 2 280 |
| NPKCM | 180 | 90 | 135 | 0 | 30 000 | 2 640 |

[a] The input of crop residue derived C = γ * Yield * $C_{stubble+roots}$, where γ is the ratio of stubble plus roots to yield.

### 2.3. Structural stability

The soil bulk density of the 0–20 cm soil layer was determined by collecting undisturbed soil samples using PVC rings (5 cm in diameter and 5 cm in height). Three core samples were taken at random from each plot.

Aggregate stability was determined by using wet sieving technique described as Elliott's (1986) method. A series of three sieves with 2.0, 0.25, 0.053 mm openings were used to obtain four aggregate size classes: (1) > 2.0 mm (large macroaggregates); (2) 0.25–2.0 mm (small macroaggregates); (3) 0.053–0.25 mm (microaggregates); (4) < 0.053 mm (silt and clay fractions). Prior to wet sieving, 100 g of < 8 mm air-dried soil was slaked for 10 min in deionized water. Subsequently, the sieve was moved manually up and down by about 3 cm with 20 times per minute for 2 min. The aggregate fractions retained on each sieve were transferred completely into a 500 ml plastic pot. All fractions were oven dried at 40 °C for 48 h and then weighed. Mean weight diameter (MWD) of each treatment was calculated by the following equation:

$$MWD = \sum_{i=1}^{n} \bar{x}_i \times w_i \tag{1}$$

where $\bar{x}_i$ is the mean diameter of each aggregate fraction; $w_i$ is the mass proportion of aggregate fraction remaining on each sieve, and $n$ is the number of fractions.