Catena 173 (2019) 38–47

Contents lists available at ScienceDirect

Catena

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

Soil wet aggregate distribution and pore size distribution under different tillage systems after 16 years in the Loess Plateau of China

Lili Gao[a,b,c], Bisheng Wang[b], Shengping Li[b], Huijun Wu[b], Xueping Wu[b], Guopeng Liang[b], Daozhi Gong[a], Ximei Zhang[a], Dianxiong Cai[b,*], Aurore Degré[c,*]

[a] Key Laboratory of Dryland Agriculture, Ministry of Agriculture, Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing 100081, PR China
[b] National Engineering Laboratory for Improving Quality of Arable Land, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, PR China
[c] University de Liège, GxABT, Terra Research Center, 2 Passage des Déportés, 5030 Gembloux, Belgium

ARTICLE INFO

Keywords:
Conservation tillage
Aggregate stability
Pore size distribution
Soil organic carbon

ABSTRACT

In the Loess Plateau of China, conventional tillage is defined as the tillage without crop residues left on the soil surface and ploughed twice a year. The use of alternative practices is a way to reduce soil erosion. Our objectives were to assess the long-term impacts of different soil tillage systems on soil physical and hydraulic characteristics, emphasizing management practices to improve the soil physical qualities (reduce bulk density and increase stability of aggregate) under the conservation tillage system in the Loess Plateau of China. Conventional tillage (CT), no tillage (NT), and sub-soiling (SS) were applied in this experiment. Soil wet aggregates distribution and stability, soil organic carbon (SOC) content, soil water retention curves and pore size distributions were measured. The results showed that in the 0–10 cm and 10–20 cm depth soil layers, NT and SS treatments showed a significantly higher proportion of wet aggregates > 250 μm (macroaggregates) compared to CT. In these two layers, the proportion of wet aggregates < 53 μm (microaggregates) was significantly higher in CT with respect to NT and SS. SOC content increased as the aggregate fraction size increased, and was higher within wet aggregates > 250 μm than within the 250–53 μm and < 53 μm (silt + clay) fractions at both depths. In addition, the conservation tillage (NT and SS) can result in improved total porosity and reduced soil bulk density compared with CT in the surface layer. Pore size distribution in CT soil was unimodal, with the maximum in the 10–30 μm matrix pores of the surface layer. However, in the surface layer the pore size distributions from NT and SS showed a dual porosity curve, with two peaks in the matrix and structural pore areas. The 10–20 cm layer showed similar pore size distributions in each treatment. After scanning the soils by micro-computed tomography, we visualized the pore characteristics. The images showed that CT reduced the long and connected macropores compared with conservation tillage. Overall, soil aggregate stability and soil macropores are most improved under conservation tillage. Conservation tillage with crop residues should be adopted instead of conventional tillage, as an effort to improve crop yield and control soil erosion in the Loess Plateau of China.

1. Introduction

The Loess Plateau accounts for one-third of the arable land in China, and plays a vital role for the agricultural production of the country (Li et al., 2016; Qiu et al., 2016). In this region, the average annual precipitation varies 200 and 750 mm. The rainfall is mainly occurring in summer (June to September) (Li and Huang, 2008; Lin and Liu, 2016), and heavy thunderstorms cause severe soil erosion and nutrient losses (Hessel et al., 2003).

Conventional tillage is the dominant tillage practice, normally ploughing twice a year with stubble removal, in this area. However, this type of tillage practice system can cause alterations to the soil physical characteristics (bulk density, aggregate stability and pore size distribution) (Hill, 1990; Tagar et al., 2017) and increase the risk of erosion (Liu et al., 2015). In order to reduce the severe erosion under conventional tillage, considerable attention has been paid recently on the conservation tillage as a long-term sustainable practice for agricultural ecosystems (Su et al., 2007).

There are many different conservation tillage systems, such as no tillage, sub-soiling and reduced tillage (Blevins et al., 1983; Holland,

* Corresponding authors.
E-mail addresses: gaolili@caas.cn (L. Gao), caidianxiong@caas.cn (D. Cai), aurore.degre@ulg.ac.be (A. Degré).

https://doi.org/10.1016/j.catena.2018.09.043
Received 22 August 2017; Received in revised form 14 September 2018; Accepted 22 September 2018
0341-8162/

Table 1
Long term tillage practices.

Treatment	Period		Depth (cm)	Stubble (cm)	Cultivar		Fertilization ($kg\ ha^{-1}$)		
	July	October			July	October	N	P_2O_5	K_2O
NT (no tillage)	–	–	–	30	–	Winter wheat	150	105	45
SS (sub-soiling)	1	–	30	30	–	Winter wheat	150	105	45
CT (conventional tillage)	1	1	20	10	–	Winter wheat	150	105	45

2004; Lal, 1997; van den Putte et al., 2012). Previous studies found that conservation tillage can improve the water content (Moraru and Rusu, 2010), and enhance soil structure and crop yields (Lampurlanés et al., 2016; Stroud et al., 2016; Su et al., 2007). Jin et al. (2008) found that conservation tillage showed promising trends in improving soil water storage and water-use efficiency in the Loess Plateau of China after 7 years. However, other studies pointed out that there was no difference in water content between conservation and conventional tillage in Iowa (USA) after 2 years (Licht and Al-Kaisi, 2005). Since soil water content changes slowly following an alternation in soil infiltration and evaporation, which depend on different soil type and climatic conditions, respectively, long-term experiments are needed to be locally assessed (Su et al., 2007). The long-term tillage experiments could also provide reliable results on soil quality.

Soil physical quality has been widely approached by those related to soil aggregates distribution (e.g., de Moraes et al., 2016), and pore size distribution and functioning (Starkloff et al., 2017) to evaluate the effects of different tillage systems. In addition, soil aggregate stability can be a signal of vulnerability and resilience for soils (Karlen et al., 1997). The stability of soil aggregates can protect SOC from mineralization, because it physically reduces the accessibility of organic compounds for microorganisms, enzymes, and oxygen (Bronick and Lal, 2005). Soil aggregate stability is generally determined by wet sieving, and expressed by mean weight diameter (MWD) (Le Bissonnais, 1996). Improving soil aggregate stability could maintain soil productivity, reduce soil degradation, and minimize environmental pollution (An et al., 2010). In addition, soil pore size distribution is regarded as another indicator of soil physical quality, related to aggregate size distribution and estimated by the soil water retention curve (Mamedov et al., 2016). The classic pore size distribution obtained from water retention curve model was proposed by van Genuchten (1980). In the van Genuchten model, the soil is assumed as a single continuous pore domain. Durner (1994) proposed a multimodal retention function to describe water retention curve by a linear superposition of subcurves of the van Genuchten type models. Currently, several studies apply bimodal methods, based on the overlap of two unimodal curves to fit the water retention curves due to the complex porous space in soils (Dexter et al., 2008; Ding et al., 2016; Romano et al., 2011). Koſodziej et al. (2016) studied different agricultural reclamation methods on a sandy loam soil and found that the dual porosity model showed a better result when compared to the van Genuchten model.

The objectives of this study were to investigate the impacts of long-term tillage systems on soil physical characteristics and hydraulic properties. We hypothesized that the conservation tillage improves soil physical properties, namely reduces bulk density, increases aggregate stability and macroporosity in the Loess Plateau of China.

2. Materials and methods

2.1. Field site description

The experiment was set up in 1999 at the experimental station of the Chinese Academy of Agricultural Science, located in the city of Luoyang (Henan province; 113.0° E, 34.5° N), China. The site (324 m ASL) has a warm temperate continental climate, with an average annual rainfall of 546 mm, and the temperature averages 13.8 °C over the year. Rainfall occurs mainly from June to September. The soil was classified as *Calcaric Cambisol* according to WRB (IUSS Working Group, 2006) with a sandy loam soil texture (clay: 15.2%, silt: 24.3%, sand: 60.5%) before the experiment setup at 0 to 20 cm. Winter wheat (*T. aestivum* L.) is the major crop. The site showed homogenous soil properties since it was conventionally tilled for > 30 years before the setup of the experiment. At the initiation of the experiment, soil samples contained an average SOC of $11.5\ g\ kg^{-1}$, total N $1.1\ g\ kg^{-1}$, total P $0.69\ g\ kg^{-1}$, and bulk density $1.3\ g\ cm^{-3}$ in 0 to 20 cm depth. Three treatments with three replicates were implemented in 9 plots (30 m × 3 m each).

2.2. Tillage systems

The experiment was designed as a randomized block design with three replications (Su et al., 2007). Long-term continuous winter wheat (wheat followed by summer fallow) was performed with the following treatments: annual no tillage (NT), annual sub-soiling (SS) (ploughing once each year with a shovel) and annual conventional tillage (CT) (ploughing twice each year with a shovel). Table 1 highlights major field operations for the tillage systems. Winter wheat (*T. aestivum* L.) is sown around October 5th, with chemical fertilizer being incorporated at the same time in three tillage systems. SS: sub-soiling is performed down to 30–35 cm depth in 60 cm intervals.

2.3. Sampling

At the site, undisturbed soil samples for water retention curves, bulk density, wet aggregate distribution, scanning and SOC content were randomly selected for each treatment from the 0–10 cm and 10–20 cm depth layers in June 2015 and stored at 4 °C.

2.4. Soil water retention curves

Three undisturbed soil samples for each treatment were taken by metal cylinders (5 cm high and 5 cm in diameter) with $100\ cm^3$ volume from 0–10 cm and 10–20 cm depth. These undisturbed soil samples were oven-dried (105 °C, 24 h) to determine soil bulk density. In addition, three samples for each treatment were taken by metal cylinders (2 cm high, 6.2 cm diameter) with $60\ cm^3$ volume from 0–10 cm and 10–20 cm depth to determine soil water retention curves. Soil samples were saturated by capillary rise and subsequently drained to fixed soil matric potentials (*h*) of −10, −40, −60, −70, −100 cm H_2O using the sandbox method (Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands) and −330, −700, −1000, −5000 and −15,000 cm H_2O using a pressure plate extractor (Soil Moisture Equipment Corp., CA, USA). The soil total porosity was calculated by the bulk density and particle density (assumed $2.65\ Mg\ m^{-3}$) values. The particle density was used as a constant value for 0–10 cm and 10–20 cm depth in our study. After calculating our data by the equation that proposed by McBride et al. (2012), the results showed that in the 0–10 cm and 10–20 cm depth soil layers, although the SOM were higher in NT and SS than CT, the particle density showed a similar result. Therefore, the particle density set a constant value in our experiment. Soil water content (θ) ($cm^3\ cm^{-3}$) at matric potentials of −330 cm and −15,000 cm H_2O were used to represent field capacity (FC) and permanent wilting point (WP), respectively (Botula et al., 2012). Available