Geoderma 230–231 (2014) 41–49

Contents lists available at ScienceDirect

Geoderma

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

Soil aggregate and crop yield changes with different rates of straw incorporation in semiarid areas of northwest China

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ARTICLE INFO

Article history:
Received 29 September 2013
Received in revised form 27 February 2014
Accepted 6 April 2014
Available online 4 May 2014

Keywords:
Crop yield
Semiarid area
Soil aggregates
Soil water storage
Straw incorporation

ABSTRACT

The current cropping system of conventional tillage and stubble removal in the northwestern Loess Plateau of China is known to decrease the water use efficiency and crop yield because of reduced aggregation and aggregate stability, as well as degrading other soil properties. To determine the effects of straw incorporation on the soil aggregates and crop yield, we conducted experiments in semiarid areas of southern Ningxia for 4 years (2007–2010). Four treatments were tested: (i) no straw incorporation (CK); (ii) incorporation of maize straw at a low rate of 4500 kg/ha (L); (iii) incorporation of maize straw at a medium rate of 9000 kg/ha (M); and (iv) incorporation of maize straw at a high rate of 13 500 kg/ha (H). In the final year of treatment (2010), the mean soil bulk density of the tilth soil (0–60 cm) was decreased significantly with H, M and L, i.e., by 4.13%, 3.21% and 1.80% compared with CK, respectively, and the treatments greatly improved the total soil porosity. The straw incorporation treatments increased the soil aggregate size distribution and soil aggregate stability in the 0–40 cm soil layers, according to the following order: H/M > L > CK. Straw incorporation significantly improved the soil moisture content compared with CK. Higher yields coupled with greater water use efficiency were achieved with H, M and L compared with CK, where these treatments increased the crop yields by 22.49%, 22.82%, and 10.62%, respectively, and the water use efficiency by 32.11%, 29.29%, and 14.05%.

1. Introduction

China has a large region of dryland farming in the northwest (Wang et al., 2012), which is constrained by adverse weather, topography, water deficiency, and infertile soils (Deng et al., 2006; Huang et al., 2005). Thus, it is important to improve the soil quality and soil water capacity, which play significant roles in promoting the crop productivity in this zone.

Since the 1980s, crop residue burning has been the traditional method for disposal after the harvest. However, crop residue burning reduces the amount of organic substances (Chan et al., 2002), the water stability of the entire soil, and the number of earthworms (Wuest et al., 2005), as well as the dry aggregates. Furthermore, this practice has led to the degradation of the agricultural ecological environment (Mandal et al., 2004). Many studies have shown that crop straw is rich in organic material and soil nutrients, so it is increasingly considered to be an important natural organic fertilizer (Tan et al., 2007; Duiker and Lal, 1999; Saroa and Lal, 2003). The addition of crop residues to cultivated soils helps to improve the soil quality and productivity via its favorable effects on soil properties (Mulumba and Lal, 2008). Jastrow (1996) and Bhattacharyya et al. (2009) observed that residue management and the artificial addition of organic matter sources to the soil and clay minerals are the most important factors that facilitate soil structural development and soil aggregation improvement. Li et al. (2006) and Tan et al. (2007) found that straw incorporation can promote a favorable soil environment for production, while also maintaining the physicochemical condition of the soil and improving the overall ecological balance of the crop production system.

Soil aggregates are the basic units of the soil structure (Scanlon et al., 2002), which can protect soil organic matter (SOM) (Chevallier et al., 2004; Jastrow, 1996; Tisdall and Oades, 1982), but they also affect the soil tilth (Horn and Smucker, 2005), regulate water flow (Horn and Smucker, 2005; Seybold and Herrick, 2001), determine the microbial biomass and mineral nutrient reserves (Ashagrie et al., 2005; Hernández-Hernández and López-Hernández, 2002; Villar et al., 2004), and reduce run-off and erosion (Barthes and Roose, 2002; Dexter, 1988; Six et al., 2000). Wagner et al. (2007) showed that the incorporation of barley straw is most effective for the development of water-stable aggregates in the soil. Compared with farmyard manure, straw incorporation improves the aggregate stability and other soil properties, as well as reducing soil detachment and improving infiltration rates (Eynard et al., 2006; Sonnleitner et al., 2003). Mulumba and Lal (2008) also reported that the addition of crop residues to cultivated

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http://dx.doi.org/10.1016/j.geoderma.2014.04.007
0016-7061/

soils had positive effects on the soil porosity, available water content, soil aggregation, and bulk density. Bhagat and Verma (1991) showed that the incorporation of crop straws for 5 years significantly increased the crop yield and improved the soil properties.

Thus, straw has positive effects on the soil quality and it can be effective in stabilizing the soil structure, in addition to its roles in soil aggregation and aggregate stability. However, the application of straw incorporation in semiarid areas of northwest China has not been reported previously. Thus, we investigated the effects of different crop straw incorporation rates combined with conventional planting on the soil bulk density and porosity, soil aggregate size distribution and aggregate stability, soil water storage, and crop yield in a loessal soil in the southern Ningxia region of northwest China.

2. Materials and methods

2.1. Site description

The experiments were conducted between 2007 and 2010 at the Dryland Agricultural Research Station, Pengyang County, Ningxia, China (106°45′N, 35°79′E and 1800 m a.s.l.). The experimental area was in a hilly and gully region of the Loess Plateau, which was characterized by a semiarid, warm temperate, continental monsoon climate. The average annual rainfall was 435 mm, which occurred mainly from June to September. The annual mean evaporation was 1050 mm and the annual temperature average was 8.1 °C with a frost-free period of 155 days.

Rainfall during the experimental period was measured using an automatic weather station (WS-STD1, Delta-T Devices, UK) at the experimental site. The monthly precipitation distributions during the experimental period are shown in Fig. 1.

The soil at the experimental site was a loessal soil with a pH of 8.5. In the 0–40 cm soil layer, the organic matter, total N, P, and K were 8.32 g kg^{-1}, 0.61 g kg^{-1}, 0.58 g kg^{-1}, and 5.4 g kg^{-1}, respectively, while the available N, P, and K were 46.25 mg kg^{-1}, 10.41 mg kg^{-1}, and 104.82 mg kg^{-1}. In 2007, the site was planted with maize prior to the experiment

The experimental field was flat and the soil was a Calcic Cambisol (sand 14%, silt 26%, and clay 60%) according to the FAO/UNESCO Soil Classification (FAO/UNESCO, 1993). The key physical properties of the soil layers (0–40 cm depth) are listed in Table 1.

2.2. Experimental design and field management

The experiment used a randomized block design with three replicates. Each plot was 3 m wide and 6 m long. The experiment included four straw incorporation rate treatments: (i) no straw incorporation (CK); (ii) incorporation of maize straw at a low rate of 4500 kg/ha (L); (iii) incorporation of maize straw at a medium rate of 9000 kg/ha (M); and (iv) incorporation of maize straw at a high rate of 13 500 kg/ha (H).

The maize straw was mixed manually with the top 25 cm of soil in the field. Before mixing with the soil, the maize straw was chopped into 5 cm pieces and applied to the soil 6 months before the crop was planted to facilitate the decomposition of the straw. The straw was incorporated into the soil layer on October 15, 2007 and after the harvests in 2008–2010. Seeding maize (cv. Shendan 16) was planted at a rate of 52 500 plants/ha in mid-April and harvested in mid-October of 2007 and 2009, and seeding millet (cv. Datong 10) at a rate of 300 000 plants/ha in 2008 and 2010.

Ten days before sowing, a basis fertilizer containing 102 kg N ha^{-1} and 90 kg P ha^{-1} was spread evenly over each plot and plowed into the soil layer. No artificial irrigation was provided during the years of the experiment. Manual weeding was performed throughout the experiment.

2.3. Sampling and measurement

The rainfall data were recorded using a standard weather station located at the experimental site. After the harvest in 2008–2010, soil samples were collected from the four incorporation treatments at depths of 0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm to determine the aggregate stability. The soil samples were collected from four points in each plot replicate and mixed to produce a composite sample. Each soil sample was passed through an 8 mm sieve by gently breaking the soil clods, where pebbles and stable clods >8 mm were discarded.

Between 2007 and 2010, the soil water content was determined in each plot by taking three random soil core samples using a 54 mm diameter steel core-sampling tube, which was driven manually to a depth of 2.0 m during each growing season (from May to October) and between November and April in the next year. The soil cores were weighed wet, dried in a fan-assisted oven at 105 °C for 48 h, and weighed again to determine the soil water content and bulk density (Ferraro and Ghersa, 2007). The gravimetric water content was

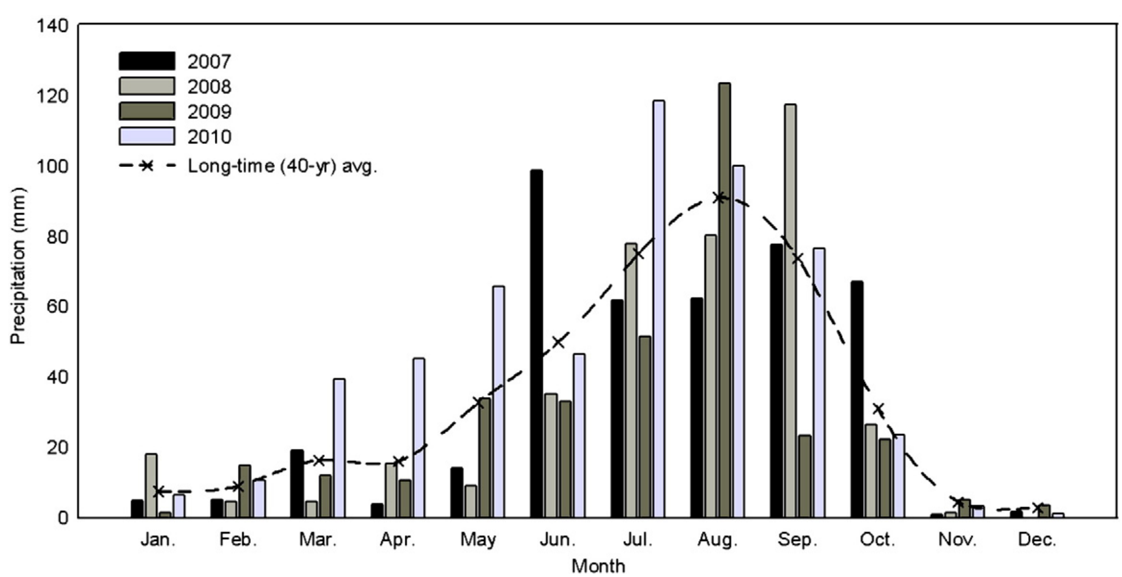

Fig. 1. Distribution of mean monthly precipitation at the experimental site during 2007–2010.