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Maize straw effects on soil aggregation and other properties in arid land

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ABSTRACT

Soil structure has been destroyed due to long-term application of inorganic fertilizer in the Loess Plateau of China. Our objective was to determine how incorporation of three different rates of maize (*Zea mays* L.) straw affected soil aggregate size and stability within the top 30 cm of arid soil on the Loess Plateau of China to provide basic theory of land utilization. Three rates of maize straw (4.5, 9.0, or 13.5 Mg ha^{-1}, hereafter referred to as LS, MS, and HS) were incorporated with 255 and 90 kg/ha of inorganic N and P fertilizer, respectively, 2 times in a 4-year field experiment. Water stability of five aggregate size classes (>5, 2–5, 1–2, 0.5–1, and 0.25–0.5 mm) in the 0–10, 10–20, and 20–30 cm depth increments was measured 3 times for each treatment and a check (CK) that received only the inorganic fertilizers. Incorporation of 13.5 Mg ha^{-1} of straw significantly increased water stability of three aggregate classes (>5, 1–2, 0.5–1 mm) compared with CK and LS treatments within the surface 10 cm and for aggregates >0.5 mm in the 10–20 cm depth increment. Within the 20–30 cm depth increment water-stablity of aggregates in the 0.25–0.5 mm class increased significantly as the rate of straw incorporation increased. Overall, aggregate stability was primarily increased through changes in microaggregate size distribution, especially for aggregate classes >5, 0.5–1, 0.25–0.5 mm within the 0–10, 10–20, 20–30 cm soil depth, respectively. Straw incorporation is a positive and effective agriculture measure to improve soil structure.

1. Introduction

Soil aggregate distribution and stability are important soil quality indicators (Six et al., 2000). Soil porosity, water-holding capacity, erosion durability are all influenced by soil aggregate structure (Bronick and Lal, 2005). Previous studies have shown that soil degeneration always starts with destroying and disappearing of aggregate structure. The quantity and size of soil water-stable aggregate are the key indicator of soil physical process such as soil compaction (Baumgartl and Horn, 1991; Lu and Li, 2002). Soil aggregate stability is also a major index reflecting the condition of soil structure, which not only has an important role in regulating and sustaining land productivity, but also has association with erosion resistance of soil and environmental quality (Abiven et al., 2009). Fertilization influences the formation and stabilization of soil aggregates (Bhattacharyya et al., 2009; Chirinda et al., 2010). Meanwhile, soil organic matter helps to improve soil structure and the formation of stable aggregates (Cui et al., 2011). Crop residue incorporation into the soil is a well-established strategy for increasing soil organic matter contents in agricultural production systems (Monaco et al., 2008; Bertora et al., 2009; Niu et al., 2011; Malhi et al., 2012), and has great impact on soil aggregate structure. Rice (*Oryza sativa* L.) straw and animal manure incorporation resulted in a high percentage of water-stable aggregates, larger mean weight diameter, and higher porosity (Verma and Bhagat, 1992). The addition of rice straw improved the formation of macroaggregates with a concomitant decline of microaggregates, and increased carbon and nitrogen content in various aggregate sizes (Benbi and Senapati, 2010). Wheat straw incorporation combined with green manure increased soil aggregation structure, increased infiltration rate, reduced the bulk density, decreased dispersion ratio and reduced soil strength accordingly (Singh et al., 2007).

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However, straw incorporation also showed the negative effects on soil aggregates. Bossuyt et al. (2001) reported that additional mineral nitrogen combined with low-quality rice residue (C/N:108) incorporation resulted in decreased macroaggregates >0.2 mm formation because of the lower microbial activity which inhibited the production of binding agents responsible for the formation of large macroaggregates. Soon and Lupwayi (2012) showed that soil water-stable aggregates >0.25 mm were decreased with straw incorporated by disking in the region of a mean annual temperature of 2.6 °C. Thus the effect of straw incorporation on soil aggregation is not clear.

Invertase enzyme activity showed rapid response to soil management practices with respect to total soil organic matter (Masciandaro et al., 2004). Additionally, measurement of soil invertase enzyme activities provides a sensitive indication of soil nutrient turnover (Goyal et al., 1993).

Therefore, the objective of this study was to investigate the effects of three rates of maize straw incorporation on soil aggregation and other soil properties in a semi-arid area.

2. Material and methods

2.1. Site description

A four-year field experiment with maize (*Zea mays* L.) was conducted in ustalfs (sand 26.8%, silt 41.9%, and clay 31.3%) in the years of 2007–2010 at the Ganjing Research Station of the Northwest A&F University, Heyang, Shaanxi China (35°24′N, 110°17′E; 850 m altitude). The mean annual temperature was 10 °C. The long-term mean annual rainfall at the site was approximately 572 mm and the mean annual potential evapotranspiration was approximately 1833 mm. Most of the rainfall occurred from July to September, and from the years of 2007–2010, the rainfall during the maize growth period (from mid-April to mid-September) was approximately 398, 351, 379 and 422 mm, respectively. Some chemical properties were measured using soil samples collected in the top 20 cm prior to the experiment in October 2006 and the results are as follows: pH 8.1, soil organic carbon 8.3 g/kg, total nitrogen (N) 0.8 g/kg, total phosphorus (P) 0.5 g/kg, total potassium (K) 8.4 g/kg, available N 46.5 mg/kg, available P 9.0 mg/kg, available K 106.2 mg/kg, electrical conductivity 0.1 ms/cm, $CaCO_3$ 21.6 g/kg, soluble carbon 48.1 mg/kg, basal respiration 1.2 umol $CO_2/m^2/s$, soil microbial biomass carbon 316.2 mg/kg, water-stable aggregates >0.25 mm 3.6%.

2.2. Experimental design

The field experiment used a completely randomized block design with four treatments, three replicates, and a plot size of 4 × 6 m. The four treatments were: (i) application of mineral fertilizers only (CK); (ii) straw incorporation to approximately 25 cm soil depth at a low rate of 4.5 t/ha in combination with mineral fertilizers (LS); (iii) straw incorporation to approximately 25 cm soil depth at a medium rate of 9.0 t/ha in combination with mineral fertilizers (MS); (iv) straw incorporation to approximately 25 cm soil depth at a high rate of 13.5 t/ha in combination with mineral fertilizers (HS). The N and P fertilizers were applied separately as basal fertilizers before sowing the maize, at rates of 102 kg N/ha and 90 kg P/ha, respectively. Additional N fertilizer was applied at a rate of 153 kg N/ha during the stage when maize had a spear-shaped top (late July). The total N and P content of the mineral fertilizers were 255 kg/ha and 90 kg /ha respectively for each treatment at each fertilization year. The mean values of maize straw nutrient contents for the four-year period were 6.0 g N/kg, 0.6 g P/kg, and 13.7 g K/kg. The maize straw at each plot was removed after harvest. The removed maize straw was cut into 15 cm long segments, uniformly covered to the plots according to the experimental design and then all plots were tilled by a moldboard plow into approximately 22 cm soil at the end of September. The maize variety used was Shendan 16. In each experimental year, maize was planted at a rate of 49,500 seeds/ha in mid-April and harvested in mid-September. No irrigation was applied in any of the experimental years.

2.3. Sampling and analysis methods

Soil samples used for soil organic matter and soil aggregates analysis were collected from soil depths of 0–10 cm, 10–20 cm, 20–30 cm in all the plots immediately after the maize harvest in September each year. In each plot, soil samples used for soil property analysis were collected from five points with the distance of 1.2 m between each sampling points and mixed to produce a composite sample of approximate 2000 g soil. The subsamples then were put on kraft paper. Gravel, animal and plant residues were picked out and soil was air-dried in a room of natural ventilation. Approximately 1700 g of this soil sub-sample was then used for aggregate analysis, approximately 150 g of the other soil sub-sample was sieved through a 0.15 mm mesh before soil organic matter and total N measurements, while the remainder was sieved through a 1 mm mesh for soil invertase activity measurements. Soil organic matter was determined using the dichromate oxidation method (Walkley and Black, 1934). Soil total N was determined by micro-Kjeldahl digestion (Guan et al., 1986). Soil invertase activity was determined using the DNS titration method (Guan et al., 1986). Soil organic matter, total N and invertase activity values were calculated on the basis of the oven-dry (105 °C) weight of soil.

The water-stable aggregates were measured on the sand-free basis. Size distribution of water-stable aggregates was determined by the wet seiving method for which a 200 g soil sample was placed on a stack of sieves (5, 2, 1, 0.5 and 0.25 mm). The stack was then immersed in water and moved up and down by 3.5 mm at a rate of 30 rpm for 15 min. The mass ratio of water-stable aggregates >5 mm, 2–5 mm, 1–2 mm, 0.5–1 mm, 0.25–0.5 mm to the total soil was calculated by drying and weighing the soil remaining on the sieves (Wang et al., 2012). In the dry sieving method, 200 g soil samples were placed on a stack of sieves (5, 2, 1, 0.5 and 0.25 mm). The stack was then shaken with a rotating speed of 270 rpm min^{-1} for 2 min by the oscillator (SHZ-82, Jintan, Jiangsu, China). The weight of soil on each sieve was measured with an electronic balance and the proportion of aggregate mass on each sieve to the total soil mass was calculated.

Mean weight diameter of soil water-stable aggregates was calculated using the following equation (Oguike and Mbagwu, 2009).

$$\mathrm{MWD} = \sum_{i=1}^{n} X_i W_i$$

Where MWD is the mean weight diameter of water-stable aggregates, X_i is the mean diameter of water-stable aggregates on each sieve size, W_i is the weight of the water-stable aggregates in each size as a fraction of the total analyzed sample weight, and n is the number of sieves.

The water-stable aggregate index reflecting aggregate stability was calculated as (Wang et al., 2012):

$$\mathrm{WSA} = \frac{W_w}{W_d} \times 100$$

Where WSA is the water-stable aggregate index which accounts for aggregate stability, W_w is the weight of wet sieved soil >0.25 mm, W_d is the weight of dry sieved soil >0.25 mm.