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RESEARCH ARTICLE

Soil shear properties as influenced by straw content: An evaluation of field-collected and laboratory-remolded soils

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Abstract

Following a rice or wheat harvest, a large amount of crop residue (straw) is retained in fields. The straw is often incorporated into the soil in order to increase the soil organic carbon storage and to reduce soil erosion. However, it has become apparent that the incorporated straw can significantly alter soil shear properties, which can dramatically affect energy inputs for tilling and other soil management practices. In this study, laboratory-remolded wheat straw-soil samples were compared with field-collected straw-soil samples; we found high correlations for the cohesion (R^2=0.9084) and internal friction angle (R^2=0.9548) properties of the samples. Shear tests on rice and wheat straw with different moisture content levels clearly demonstrated the relatively higher shear strength of wheat straw compared to rice straw. The cohesion of remolded rice and wheat straw-soil samples exhibited an increasing linear trend with an increase in densities, whereas the internal friction angle data for these samples exhibited a quadratic trend. Overlapping the cohesion curves revealed that the wheat straw-soil and rice straw-soil samples had the same cohesion at a straw density of 0.63%. Similar results were obtained when the internal fraction angle curves overlapped; the resultant point of intersection was observed at a straw density of 0.46%. As a whole, the remolded sample methodology was found suitable to simulate the shear properties of soils sampled directly from fields.

Keywords: direct shear test, wheat straw, rice straw, cohesion, internal friction angle

1. Introduction

Rice and wheat are the two main cereal crops in China; their production accounts for 80% of the total national grain production (Yang *et al.* 2000). After harvesting these crops, the residues (straw) remaining in the field have high levels of both organic content and many nutrients. Straw is therefore considered to be an important source of natural organic fertilizer (Tan *et al.* 2007). In an effort to make use of this important resource, farmers often incorporate straw into the soil. Additional benefits of this practice include increasing the soil organic carbon storage capacity (Zhang *et al.* 2014) and reduction in soil erosion (Foltz *et al.* 2012). However, we know that the incorporation of straw into the soil, either directly or indirectly, alters the shear properties of the soil (Li *et al.* 2002).

The Chinese government has promoted conservation tillage practices since 2002 in an effort to minimize energy inputs in agriculture (Zhang *et al.* 2004). As the presence of straw affects soil shear strength and therefore directly im-

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pacts tillage force, the effects of straw incorporation into soils on energy consumption and on soil failure patterns need to be studied and quantified (Tagar *et al.* 2015). Soil shear strength is a property that strongly affects soil deformation and draft forces. Shear strength is known to depend on both soil cohesion and the internal friction angle (Mckyes 1985). It has been reported that the presence of straw in the soil, and the resulting changes in soil shear properties, greatly increases the required draught force, horizontal force, and vertical force needed during the tillage process (Kushwaha *et al.* 1986; Farid Eltom *et al.* 2015).

Although researchers have previously focused on the biological and mechanical properties of straw (O'Dogherty *et al.* 1995; Taghijarah *et al.* 2011; Chandio *et al.* 2013a, b), little information is available regarding the impact of straw on soil shear properties. One study that did address these questions was reported by Qu *et al.* (2013); they incorporated 15 mm of wheat straw with a 0.3% straw density in soil, and found that this treatment increased soil shear strength. Given that huge amounts of both wheat and rice straw are produced each year, and considering that the amount produced is almost certainly in excess of the required amount needed for an optimized incorporation strategy (Bi *et al.* 2009), further studies are needed to establish an empirical basis for designing straw incorporation recommendations that properly managing both the known benefits and the potential increased energy costs associated these practices. To our knowledge, no one has previously tried to correlate the shear properties of laboratory-remolded straw-soil samples with straw-soil samples collected from field conditions. Therefore, we conducted a study with the aim of examining correlations among the shear properties of both field-collected and laboratory-remolded straw-soil samples to investigate the impact of straw type and density on soil shear properties in an agronomically-relevent way.

2. Materials and methods

The rice straw (Wuyunjing 23) (RS) and wheat straw (Nanjing 16) (WS) were obtained at the time of harvesting. The soil samples were taken both before and after the incorporation of wheat straw. Both the straw and soil samples were from Jiangpu Agricultural Experimental Farm of Nanjing Agricultural University in Jiangsu, China. The soil was comprised of 39.4% sand, 32.7% silt, and 27.9% clay and therefore classified as clay loam according to international soil textural classification. The average dry bulk density of soil was (1.57±0.05) g cm^{-3}. The moisture content of wheat and rice straw was (19.6±2.1)%, the moisture content of soil was (24.6±0.7)%, while the moisture content of the soil-straw sample was (23.3±1.0)%.

The experiments were conducted in 2014–2015 at the Agricultural Material Characteristics Research Laboratory (shear strength of straw) and the Soil Mechanics Laboratory (cohesion and internal friction angle of soil and straw-soil samples). Both of these laboratories are part of the Department of Agricultural Mechanization of the College of Engineering of Nanjing Agricultural University in Jiangsu, China.

2.1. Sample preparation

Field samples The mass percentage of wheat straw in the straw-soil samples taken after incorporation were 0, 0.47, 0.66 and 0.92%, respectively, as shown in Fig. 1.

Remolded samples It is extremely difficult to simulate actual field conditions in the laboratory, as straw remains in fields at random positions following harvesting, and the tillage process presumably incorporated straw into soil randomly. To approximate the field situation, WS and RS were chopped manually into 20-mm pieces (equal to the height of cutting ring). These pieces were inserted uniformly into field soil vertically to simulate the actual situation of the field as far as possible and yet ensure experimental reproducibility. We prepared five types of straw-soil samples by inserting 9, 16, 23, 30, or 37 pieces of straw into a soil sample, resulting straw densities of, respectively, 0.27, 0.48, 0.70, 0.91, and 1.12% for WS (Fig. 2). We also thusly prepared 5 types of RS-soil samples; these had densities of 0.41, 0.74, 1.06, 1.38, and 1.70%.

2.2. Direct shear test

The shear properties of the soil samples and the soil-straw samples were determined using a direct shear box (SDJ-1 strain-controlled, Nanjing Soil Instrument Co., Ltd., Nanjing, China) at Soil Mechanics Laboratory.

2.3. Shear test of straw

Shear test of straw samples was performed under different sample moisture contents, as the moisture content of straw was not the same. These tests were performed with a TMS-PRO computer-controlled texture analyzer (FTC, Inc., USA). A shear box (130 mm×90 mm×25 mm) was designed with a sliding plate that could move freely. A series of holes with diameters ranging from 3 to 7 mm were drilled through the box to accommodate the straw samples with differing internodes diameters. The shear box was attached to TMS-PRO texture analyzer *via* a testing platform at the bottom and a sliding plate fixed at the upper side (Fig. 3).

The sliding plate was loaded at the rate of 10 mm min^{-1} and the applied force was measured with an ILC-S load cell; a force-time record was obtained throughout the period up until the failure of the straw. The ultimate shear strength,