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Effects of rice-husk ash on soil consistency and compactibility

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ABSTRACT

The use of rice-husk ash (RHA) as a soil amendment is new and its effects on soil mechanical properties has not been well studied. This laboratory study aimed to assess the effects of rice-husk ash with different rates of 0%, 10%, 20%, and 30% (v/v) on soil consistency limits and soil compactibility parameters in soils with different textures. Rice-husk ash applications in all experimental soils significantly ($p < 0.05$) increased liquid limit (LL) and plastic limit (PL) values. The effectiveness of rice-husk ash on LL and PL was more pronounced in soils with low clay content. As compared with the control, the highest application dose of rice-husk ash (30%) increased LL with the rates of 29.1%, and 25.9%, in HA (Halaquept) and PL (Plagganthrept), respectively. But, the highest LL values were obtained from 20% rice-husk ash application in UD (Udifluvent). On the average, rice-husk ash application increased PL by 3.4%, 10.3%, and 14.1% with 10%, 20%, and 30% application rates, respectively, as compared to the control. Rice-husk ash application decreased maximum dry bulk density (MBD), but increased optimum water content (OWC). In all the soils studied, the lowest MBD and the highest OWC were obtained from the highest application dose of rice-husk ash. As compared with the control, the highest rice-husk ash application dose (30%) decreased the MBD with the rates of 7.2%, 8.8%, and 9.0%, in HA, PL and UD, but it increased the OWC values with the rates of 21.6%, 31.9%, and 25.5%. The findings presented in this study clearly showed that the application of rice-husk ash increases the soil resistance to mechanical forces, since an increase in OWC may imply that soil is more easily tilled in higher moisture contents without any deformation which also provides higher workable range.

1. Introduction

Soil amendments vary greatly in their origin, composition, application rate and expected or claimed mode of action (Wallace and Terry, 1998). These actions include: improvements in soil structure, aeration and drainage, increasing soil water holding capacity, reducing soil compaction, tillage and hardpan conditions, higher workability range, encouraging root development and increasing yield. Many organic and inorganic soil amendments have been extensively used for improving soil characteristics. As a soil conditioner, the use of rice-husk ash (RHA), a horticultural grade medium for all application, is not so common. Rice-husk ash is a powder obtained by burning of rice-husk, an agricultural by-product, at a temperature less than 1000 °C. China is one of the largest countries planting rice, with an annual rice-husk productivity of about 39 million tons, being plenty of rice-husk resource (Chen, 2012). Although there are many practical or potential industrial uses, the natural stacking or burning of rice-husk is the general processing method for most of the rice-processing companies, which not only occupies the land resource, but also leads to environmental pollution and a fire potential. It has been one of the main concerns for environmental agents and rice processors. The rice-husk ash obtained by burning rice husk under 1000 °C is loosely consisted of nano-scale SiO_2 gel particles (about 50 nm) in diameter. Therefore, the introduction of rice-husk ash into farming loam can not only give play to the physical filling effect, improve the particle size distribution of soil, but also promote the second hydration reaction by its high chemical activity, increasing the workability range and reducing the compactability of loam (Chen, 2012).

In this study, the Atterberg limits and the Proctor compaction of different types of local soils were focused on to evaluate their effects on soil behaviors. The Atterberg limits and the Proctor compaction test are used by agricultural engineers for classifying soils. Various authors have proposed to derive soil workability estimates using existing data from standard soil testing methods, water retention data (Dexter and Bird, 2001), consistency limits (Mueller et al., 1990), and Proctor compaction test data (Wagner et al., 1992). Soil consistence is described in terms of the soil conditions at different water states, from dry to viscous. Soil consistency has important implications to agricultural, engineering, and industrial uses of the soil (Hemmat et al., 2010; Lal and Shukla, 2004). Few agronomists have used consistency limits in their compaction research (Mapfumo and Chanasyk, 1998; Mosaddeghi et al., 2009). With the help of consistency limits, the optimum and workable water content range for tillage operations without undue effort and with minimum risk of structural damage could be determined (Dexter and Bird, 2001). Many studies showed that a significant and positive correlation exists between optimum soil water content for tillage and

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PL (plastic limit) and/or LL (liquid limit) (Barzegar et al., 2004; Dexter and Bird, 2001; Mueller and Schindler, 1998a; Mueller et al., 1990, 2003; Reeve and Earl, 1989; Terzaghi et al., 1988). Plastic (PL) and liquid limits (LL) are useful because they are direct measures of soil mechanical behavior and represent an integration of soil properties (Soane et al., 1972), which can be used to estimate properties such as compressibility (Ball et al., 2000).

Another parameter that can be used to depict the mechanical behavior is the compactibility of soil. Compactibility can be defined as the increase in density with increasing applied stress. Several factors such as soil texture, inherent bulk density, structural stability, organic matter, soluble salts and most importantly water content and compactive effort influence soil compactibility (Thacker et al., 1994). These factors also influence soil workability (Larson et al., 1994). The soil workability status is clearly related to the moisture content at the plastic limit (Dexter and Bird, 2001; Mueller and Schindler, 1998b; Smedema, 1993). The workable soil water content is a little lower than PL (Godwin and Spoor, 1977; Spoor and Godwin, 1977). Dexter and Bird (2001) reported that the optimum soil water content for tillage occurs near the 0.9PL. Keller et al. (2007) found values of optimum soil water content for tillage in the range 0.7–0.9PL on four different Swedish soils. Maximum water contents for optimum soil workability are nearly 0.6–0.9PL, or the water content at maximum Proctor density (Mosaddeghi et al., 2009; Mueller et al., 2003). The optimum water content varies with the property of the soil, but in general, it lies in the vicinity of plastic limit of the soil (Huang et al., 2009). Some researchers also related soil workability and trafficability to the Proctor compaction test (Wagner et al., 1992). The Proctor test has been employed to characterize resistance of agricultural soils to compaction and for evaluating the compaction status of soils (De Kimpe et al., 1982; Ekwue and Stone, 1995, 1997; Felton and Ali, 1992; Hakansson and Lipiec, 2000; Thomas et al., 1996; Wagner et al., 1994; Zhang et al., 1997). Parameters to compare compactibility of soils are the maximum soil bulk density (MBD) under the Proctor test and the optimum water content (OWC) at which the maximum soil bulk density is reached. The agronomic importance of these parameters is elucidated by Wagner et al. (1994). Wagner et al. (1992) also found that the best soil fragmentation in tillage is obtained at the Proctor optimum water content.

As tillage plays a significant role in agricultural crop production, it should be scheduled carefully in order to obtain the optimum soil structure. The response of soil structure to tillage crucially depends on the soil water content. When tilled outside of these limits, not only large clods can be produced but also soil structural damage can occur. Wagner et al. (1992) appointed the Proctor critical water content as the optimum water content for tillage. Mueller et al. (2003) also found a strong relationship between the soil workability and the Proctor critical water content. Increase in liquid limit (LL), plastic limit (PL), and the Proctor optimum water content (OWC) will not only cause less compactable and more easily tilled soils, but also higher workable range and more soil resistance to mechanical forces, which are mainly dependent upon soil water suction. Therefore, the objective of this study was to determine the effects of rice-husk ash application on consistency limits (LL, PL, and PI) and the Proctor compaction test parameters and indirectly to probe the effect of rice husk ash on soil mechanical forces.

2. Materials and methods

This paper evaluates the effects of rice-husk ash (RHA) on some mechanical properties of Shanghai soil. This study was conducted under laboratory conditions with a relative humidity of 65 ± 5% and an average temperature of 21 ± 2 °C. The experimental soil samples were collected from the 0 to 20 cm depth of commonly distributed soil great groups in the agricultural fields of Shanghai, China (31°14′N, 121°29′E). Soils were classified as Halaquept (HA), Plagganthrept (PL), and Udifluvent (UD) according to Keys to Soil Taxonomy (2003, Ninth Edition) issued by the United States Department of Agriculture (USDA).

The soil samples were air-dried and crumbled to pass a 4 mm sieve. Rice-husk ash passed through a 2 mm sieve was applied with the rates of 10%, 20%, and 30% on volume/volume (v/v) basis, corresponding to weight/weight (w/w) basis of 2.0%, 3.9%, and 5.9% for HA, 2.5%, 4.9%, and 7.4% for PL and 2.4%, 4.8%, and 7.1% for UD. Soil and rice-straw ash with defined amounts were uniformly mixed and conveyed to the experimental pots. The control soil without rice-straw ash application was also mixed itself in order to reduce experimental errors on structural parameters because of mixing. The mixtures were then filled into thirty six plastic containers (40 cm in length and 25 cm in wide) to a depth of 15 cm. Soils were incubated for three months at near field capacity by adding water with 3 days intervals under constant laboratory conditions.

The rice-husk ash (RHA) was an industrial waste residue from Kaidi Green Energy Power Plant. It is a powder obtained by burning the rice husk, an agricultural by-product, at about 1000 °C. The rice-husk ash was black–gray powder, which had a 76% residue on 45 μm sieve, 42% residue on 63 μm sieve, and with a loss on ignition of 5%. Table 1 shows the chemical composition of rice-husk ash. It can be seen fromTable 1 that the main component of rice-husk ash is SiO_2. While the SiO_2 in rice-husk represents an amorphous state, it demonstrates certain potential activity (Chen et al., 2011). Table 2 shows the general characteristics of the soils prior to the experiment.

Particle size distribution was determined using the sieving method; pH and electrical conductivity were measured according to McLean (1982) and Rhoades (1982a). Soil organic matter was determined using the Smith–Weldon method (Nelson and Sommers, 1982). Lime content of the soils was determined with “Scheibler Calcimeter” as described in Nelson (1982). Cation exchange capacity was determined with flame photometer using sodium acetate–ammonium acetate buffered at pH 7 (Rhoades, 1982b). Bulk density was determined as described by Blake and Hartge (1986). The Casagrande device was used to measure the liquid limit (LL), by the three-point Casagrande method. The plastic limit (PL) was determined using “the 3-mm rod formation method” (McBride, 1993). The difference between LL (liquid limit) and PL (plastic limit) is defined as plasticity index (PI). The standard Proctor method (ASTM, 1992) was applied. Subsamples of about 2.5 kg were spray moisturized in order to reach at least eight different water contents. Following the method, amounts of soil from these homogenized wet subsamples were compacted in three layers in a compaction chamber, volume of 0.911×10^{-3} m^3. Each layer received 25 blows of a 2.5 kg falling hammer from 0.305 m height. The weight of the wet compacted soil in the chamber was determined. Then the samples were dried in an oven at 105 °C for 24 h, and weighed again to estimate the moisture content and dry bulk density.

Size distribution of soil aggregates was determined using the dry and wet-sieving methods developed by Kemper and Rosenau (1986). Air-dried aggregates were separated by placing 100 g of air-dried soils on the top of a stack of five sieves (5, 2, 1, 0.5 and 0.25 mm in diameter). The soils were sieved for 10 min on a ro-tap sieve. Dry aggregates remaining on each sieve were collected and weighed. Water-stable aggregates were estimated following the standard wet-sieving method. Briefly, 50 g composite soil samples representing each dry aggregate size class were placed on the top most of a nest of sieves with diameters equaling to 2, 1, 0.5, and 0.25 mm, respectively. The sieves were placed in a sieve holder of the Yoder type aggregate analysis machine (DM200-II) and sieved in water for 30 min at a rate of 30 cycle/min. The resultant aggregates on each sieve were dried at 105 °C for 24 h and weighed. According to the size range of 5–2, 2–1, 1–0.5, and 0.5–0.25 mm, respectively, the percentage of water-stable aggregate was determined. The mass of <0.25 mm aggregate was calculated by the difference between

Table 1
Chemical component of rice-husk ash (%).

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	P_2O_3	Cl^{-1}
quantity	87.89	0.66	0.55	2.41	0.56	2.5	0.14	0.3	0.82	0.25