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Hydro-Physical Properties of a Typic Hapludult under the Effect of Rice Husk Ash

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ABSTRACT: The combustion of rice husk generates a partially burnt mixture called rice husk ash (RHA) that can be used as a source of nutrients to crops and as a conditioner of soil physical properties. The objective of this study was to evaluate the effect of RHA levels on the hydro-physical properties of a Typic Hapludult. The experimental design was composed of random blocks with four replications, which comprised plots of 24 m^2 and treatments with increasing RHA rates: 0, 40, 80 and 120 Mg ha^{-1}. Undisturbed soil samples were collected in the soil layers of 0.00-0.10 and 0.10-0.20 m after nine months of RHA application, using steel cylinders (0.03 m of height and 0.047 m of diameter). These samples were used to determine soil bulk density (Bd), total soil porosity (TP), soil macroporosity (Ma), soil microporosity (Mi) and the available water capacity (AWC). Disturbed soil samples were collected to determine the stability of soil aggregates in water, mean weight diameter of water stable aggregates (MWD), and soil particle size distribution. The results show that, as the RHA rate increased in the soil, Bd values decreased and TP, Ma and MWD values increased. No effect of RHA was found on Mi and AWC values. The effects of RHA on the S parameter (Dexter, 2004), precompression stress and compression index (Dias Junior and Pierce, 1995) values are consistent those shown for density and total porosity. Rice husk ash was shown to be an efficient residue to improve soil physical properties, mainly at rates between 40 and 80 Mg ha^{-1}. Rice husk ash reduces bulk density and increases total porosity, macroporosity and soil aggregation, but does not affect microporosity, field capacity, permanent wilting point, and available water capacity of the soil. The effect of rice husk ash on the S parameter, precompression stress and index compressibility coefficient values are consistent with those observed for the bulk density and total porosity.

Keywords: bulk density, soil porosity, available water capacity, soil compressibility, soil aggregation.

INTRODUCTION

Brazil is among the top 10 producers of rice globally, with an annual production of 11.8 million tons of grain in the husk (Conab, 2013), of which 68.7 % is produced in Rio Grande do Sul (IRGA, 2014). Considering that rice husk takes up on average 22 % of the total weight of rice (Umamaheswaran and Batra, 2008), 2.6 million tons of rice husk are produced annually in Brazil. Due to its high calorific value and low cost, rice husk has been used as a source of energy (Capeletto, 2012) resulting in a new solid waste, the rice husk ash (RHA). Since RHA is equivalent to 17 % of the dry mass of the husk (Chandrasekhar et al., 2006), the production potential of RHA in Brazil is 0.44 million tons per year.

The most striking feature of RHA is the high content of amorphous silica, i.e. around 90 % SiO_2 (Chandrasekhar et al., 2005). Thus, there has been intense research into technological processes for obtaining pure silica and other products for diverse uses (Gorthy and Mukunda, 1999; Chandrasekhar et al., 2005; Zemnukhova, 2005; Della, 2006). Rice husk ash is also used as an adsorbent material in wastewater treatment (Farook and Ravendran, 2000), as an additive in concrete and in the development of materials for construction (Gonçalves and Bergmann, 2007). However, the use of RHA on the industrial scale is still limited to a small fraction of the amount produced. Therefore, its use in agriculture is a very promising and appropriate disposal method for this waste.

The immediate effects of RHA in soil are acidity correction and supply of nutrients. The potential of RHA as a corrective for soil acidity and as a source of P and K for plants has been demonstrated, but rate are high rates are necessary (Silva et al., 2008; Islabão, 2013; Islabão et al., 2014). Such effects are expected due to the alkaline nature of RHA; as a crop residue, it has all the essential elements in its composition. However, due to the physical and chemical nature of RHA, it is not expected to react with the soil, thus the effects of RHA on physical properties of soil are not so obvious. Nevertheless, Salé et al. (1997), Ramesh et al. (2008) and Karmakar et al. (2009) observed that soil bulk density decreased following application of RHA. The RHA reduced resistance to penetration and increased total porosity and water availability (Masulili et al., 2010), although Pauletto et al. (1990) found that RHA does not affect soil water retention.

Compaction is a problem that limits the development and productivity of crops in many soils. In the Rio Grande do Sul, Typic Hapludult with sandy loam, the A horizon is usually has a density higher than 1.6 Mg m^{-3}, total porosity of approximately 35 % and macroporosity less than 10 %, as demonstrated by Teixeira et al. (1998), Cruz et al. (2003) and Dupont (2011).

In these soils, the hypothesis is that the RHA can modify the soil physical attributes to appropriate values for plants development. In view of this, the aim of this study was to evaluate the effect of RHA rates on some physical properties in the 0.00-0.20 m layer in a Typic Hapludult.

MATERIAL AND METHODS

The experimental area is located at the Agricultural Center of Palma, which belongs to the Federal University of Pelotas (UFPel), situated in the Capão do Leão municipality, Rio Grande do Sul State, Brazil; the coordinates are E357.860 N6.480.490, UTM zone 22 datum WGS84. The soil is an *Argissolo Vermelho-Amarelo* (Santos et al., 2013), a Typic Hapludult (Soil Survey Staff, 2014) with a sandy loam texture in the layer of 0.00-0.20 m. The chemical and physical characteristics are described in table 1.

The experimental design was a randomized complete block design with four replications, comprising plots of 24 m^2 (6 × 4 m) and four treatments consisting of 0, 40, 80 and 120 Mg ha^{-1} as the RHA rate. In April 2010, RHA was applied to each experimental plot using a 0.80 × 0.60 × 0.54 m wooden box, with a total volume of 260 dm^3. Setting the average dry ash density value at 0.184 kg dm^{-3}, each box was estimated to have 48 kg of RHA (equivalent to 20 Mg ha^{-1} RHA). The use of the wooden box made it easy to carry and distribute RHA, which was incorporated using rotary tiller equipment at the 0.00-0.10 m layer.

For the chemical characterization of RHA, the content of silicon (Si) was determined by X ray fluorescence spectrometry (EDX-720). The organic carbon (Walkley-Black method) and total nitrogen (Kjeldahl method) contents of RHA as well its pH and calcium carbonate equivalent (CCE) were determined according to Tedesco et al. (1995). To determine the contents of K, Na, Ca, Mg, Al, P, S, Cu, Fe, Mn and Zn, samples were digested in bi-distilled nitric acid and hydrofluoric acid (PA) and the determination was carried out through inductively coupled plasma optical emission spectrometry (ICP OES) (Perkin Elmer Optima 4300 DV) at the Environmental and Industrial Chemistry Laboratory - LAQIA at Federal University of Santa Maria, Santa Maria, RS, Brazil. The chemical composition of the rice husk ash used in this study were in table 2.

Undisturbed soil samples were collected in the depth layers of 0.00-0.10 and 0.10-0.20 m, nine months after the application of RHA, using steel cylinders (0.03 m of height and 0.047 m of diameter). To determine the soil water retention curves (SWRC), in each layer, three replications were randomly taken along the plot, totaling 12 replications per treatment. Soil water contents (θ) were measured at the tensions of 1 and 6 kPa, using a tension table apparatus, and at the tensions of 10, 33, 102 and 1530 kPa using a Richards pressure chamber (Klute, 1986).

Soil total porosity (TP), macroporosity (Ma), microporosity (Mi) and soil bulk density (Bd) values were obtained according to Donagema et al. (2011). The available water capacity (AWC) was calculated considering θ obtained by SWRC and adjusted by the van Genuchten (1980) model at tensions of 10 kPa (taken as the field capacity) and 1,530 kPa (taken as the permanent wilting point) (Reichardt and Timm, 2012). The values of the S parameter (Dexter, 2004) were calculated based on the water retention curves (gravimetric water content), using the model of van Genuchten (1980) in an SWRC computer program (Dourado Neto et al., 2000).

Table 1. Soil chemical properties and particle size distribution of a Typic Hapludult in the 0.00-0.10 and 0.10-0.20 m layers

pH(H$_2$O)	OC	K$^+$	Ca^{+2}	Mg^{+2}	Na$^+$	CECpH7.0	BS	Clay	Silt	Sand
	g dm^{-3}			mmol$_c$ dm^{-3}			%		g kg^{-1}	
				0.00-0.10 m						
5.54	11.30	1.64	23.60	10.51	0.80	76.19	49.17	169	225	606
				0.10-0.20 m						
5.23	9.85	1.21	27.4	11.30	0.82	70.56	59.12	193	220	587

pH in water (1:2.5); OC: organic carbon content (Walkley-Black method); K and Na: extracted by Mehlich-1; Ca and Mg: extracted by 1 mol L^{-1} KCl; CEC: cation exchange capacity (extracted by 0.5 mol L^{-1} calcium acetate pH 7.0); BS: base saturation; Clay, silt and sand: pipette method.

Table 2. Chemical composition of the rice husk ash used in this study

pH	PN	Si	K	Na	Ca	Mg	Al	C	N	P	S	Cu	Fe	Mn	Zn
	%					g kg^{-1}							mg kg^{-1}		
8.6	0.91	410.5	11.35	6.83	6.02	4.20	0.23	72.3	0.98	2.64	3.52	7.5	480	1278	34

PN: power neutralization.

Disturbed soil samples were also collected in the depths of 0.00-0.10 and 0.10-0.20 m to determine the stability of the aggregates in water and the particles size distribution particles (clay, sand and silt contents). To determine the distribution of the stable aggregates in water at different size classes and the mean weight diameter of water stable aggregates (MWD), samples were sieved through a 9.52 mm mesh, using the method described by Kemper and Rosenau (1986) and adapted by Palmeira et al. (1999), which employs the Yoder (1936) vertical oscillation device. The size distribution of soil particles and clay dispersed in water were determined by the pipette method (Gee and Bauder, 1986). Based on the clay and dispersed clay in water (DC) contents, the flocculation degree (FD) was also calculated.

For the uniaxial compression tests, samples were saturated through capillary for 24 h and equilibrated at the tension of 10 kPa using pressure chambers. Subsequently, static pressures of 25, 50, 100, 200, 400, 800 and 1,600 kPa were applied, according to the method described by Silva et al. (2007), and the displacement at each applied pressure was recorded using an automatic consolidometer (Model CNTA-IHM/BR, Masquetto Automação Agrícola). The soil samples were oven dried at 105 $^{\circ}$C for 24 h and soil bulk density was calculated (Donagema et al., 2011). The soil compression curve was graphically constructed plotting the logarithm of the applied loads (x axis) and soil bulk density values (y axis) for each sample. Precompression stress (σp) and compressibility coefficient (Cc) values were calculated according to Dias Junior and Pierce (1995). In order to eliminate the initial soil compaction effect, soil compression curves were normalized by dividing the soil bulk density at the end of each applied pressure by the soil bulk density obtained in the field.

To evaluate the relationship between soil physical properties and rates of RHA, linear and quadratic models were fitted using the software Sigma Plot (Sigmaplot, 2004) using the F test at the 5 % significance level. Pearson correlation coefficients were assessed out to relate MWD and the physico-chemical properties of the soil under RHA.

RESULTS AND DISCUSSION

An increase in RHA rate caused a decrease in bulk density (Bd) in the 0.00-0.10 m layer, but there was no effect on Bd values in the 0.10-0.20 m layer (Figure 1a). An increase in the carbonized rice husk proportion resulted in a reduction in Bd was found by Guerrini and Trigueiro (2004). Figure 1a also shows that the mean value of Bd (1.68 Mg m^{-3}) when the RHA rate was 0 Mg ha^{-1} is very close to the critical Bd value (BDc) suitable for the development of a crop root system in sandy loam soils (1.70 to 1.80 Mg m^{-3}), as stated by Reichert et al. (2003). Using the equations proposed by Reichert et al. (2009) for estimating BDc based on the contents of clay or clay plus silt, for three methods of determination [considering the least limiting water range, values obtained under field conditions and equations developed by Jones (1983)], obtained values around 1.6 Mg m^{-3}. These values have similarities to this study.

With the increasing RHA rates, there was an increase in total soil porosity (Figure 1b) and macroporosity mean values (Figure 1c) in the 0.00-0.10 m layer. On the other hand, there was no effect of increased RHA rates on microporosity values measured in both soil layers (Figure 1d).

Rice husk ash is a low-density material (0.184 Mg m^{-3}); therefore, as the proportion of this material in the soil increases, the porosity increases and bulk density decreases. An effect of RHA in relation to a reduction in density and an increase in total porosity was observed by Masulili et al. (2010). Salé et al. (1997) and Ramesh et al. (2008) also observed a decrease in bulk density using fly ash.
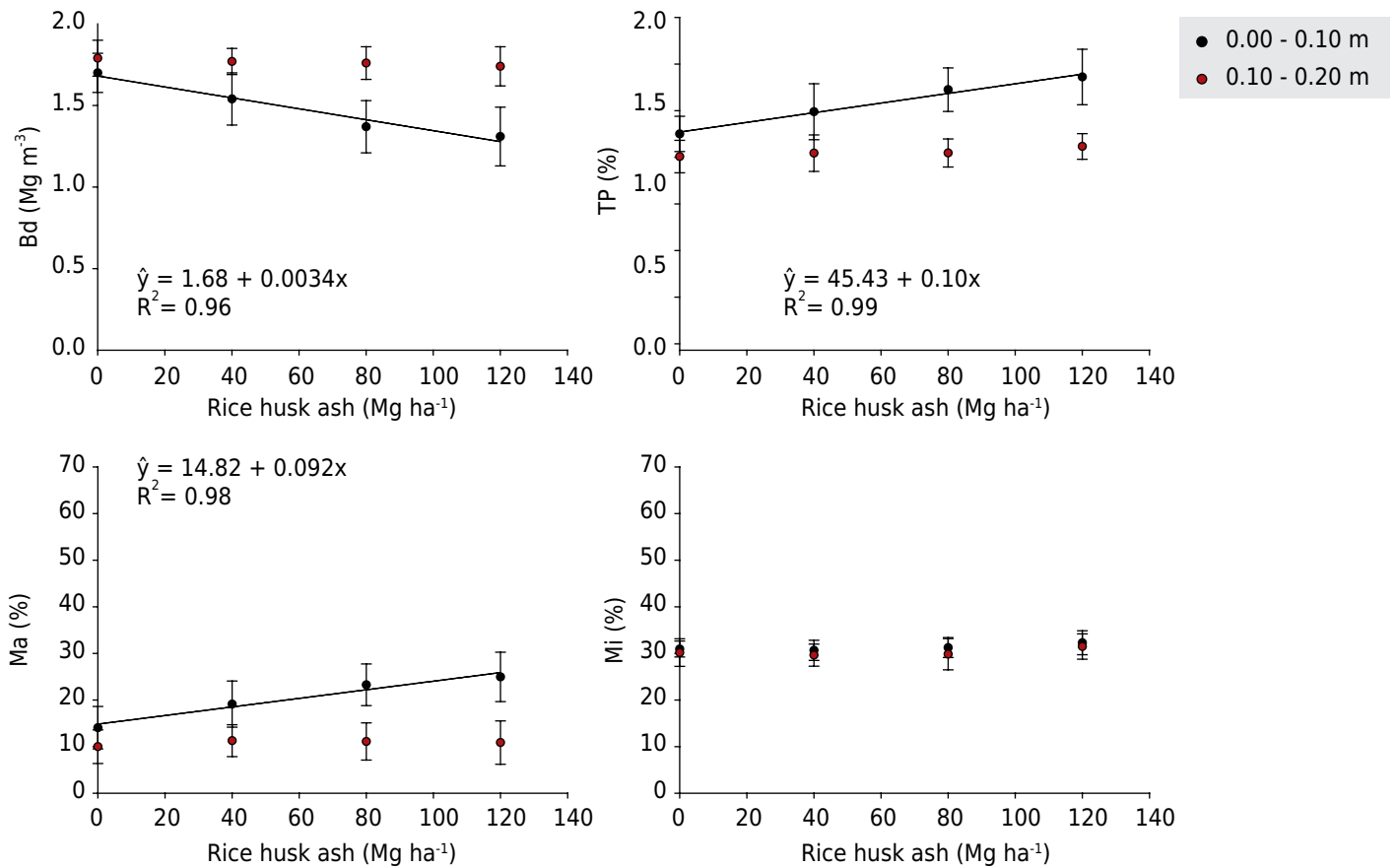
Figure 1. Mean values of (a) soil bulk density (Bd), (b) total porosity (TP), (c) macroporosity (Ma) and (d) microporosity (Mi) of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 and 0.10-0.20 m layers. Vertical bars indicate the standard deviation.

Rice husk ash increased the concentration of stable aggregates in water in the 0.00-0.10 m layer, presenting the greatest effect between the 0 and 40 Mg ha^{-1} rates (Figure 2a). The results show that, up to the third class aggregates (1.99-1.00 mm), aggregation remained stable with increasing application of RHA; that is, a higher RHA rate did not promote soil disaggregation. In the 0.10-0.20 m layer, certain uniformity in the concentration of stable aggregates in water was observed in different classes with an increase in RHA rate (Figure 2b). In studies with rice husk biochar, Lu et al. (2014) also founded an increase in macroaggregates with a diameter greater than 0.25 mm and a reduction in microaggregates with a diameter less than 0.25 mm.

In the 0.00-0.10 m layer, there was an increase in the MWD values with an increase in RHA rate (Figure 3). Lu et al. (2014) found that an increase in the rate of rice husk biochar resulted in higher values of MWD. This fact was attributed to a decrease in the aggregate breakdown by differential swelling and an increase in aggregate resistance to mechanical breakdown.

The highest MWD value presented in the 0.10-0.20 m layer was due to the prior management, as it had been tilled for at least five years. Compact soils can present high aggregate stability in water and, consequently, higher MWD values (Conte et al., 2011).

Mean weight diameter of water stable aggregates values were positively related to the clay content in the soil in both layers. Clay is the most important granulometric fraction for soil aggregation. Physico-chemical processes of aggregation are mainly associated with the clay fraction (Brady and Weil, 2008).

The flocculation degree (FD) was positively related to the MWD in both layers, which might be explained by the relation between the clay and clay dispersed in water contents

of the soil (Table 3). Clay content, and the clay dispersed in water (DC) did not present a significant correlation with MWD in any of the layers (Table 3).

As previously observed, in the 0.00-0.10 m layer, an increase in RHA rate increased TP and MWD but decreased Bd. This relation was confirmed in the MWD correlation with these variables; and increase in soil MWD increases TP and decreases Bd. The MWD in the 0.10-0.20 m layer was positively correlated to organic carbon (Table 3); this is due to the fact that the organic matter acts as an aggregation agent, mainly of macroaggregates (Tisdall and Oades, 1982). This relation between OC and MWD can be confirmed by the fact that the sub-superficial layer also presented higher MWD values.

In the 0.00-0.10 m layer, only for tensions lower than 6 kPa, there were changes in the soil water retention curve (WRC) with an increase of RHA rate (Figure 4a), possibly due to variations in soil macroporosity (Figure 1c). Probably due to the non-incorporation of ash in the 0.10-0.20 m layer, there was no significant variation in the WRC with an increase in RHA rate (Figure 4b).
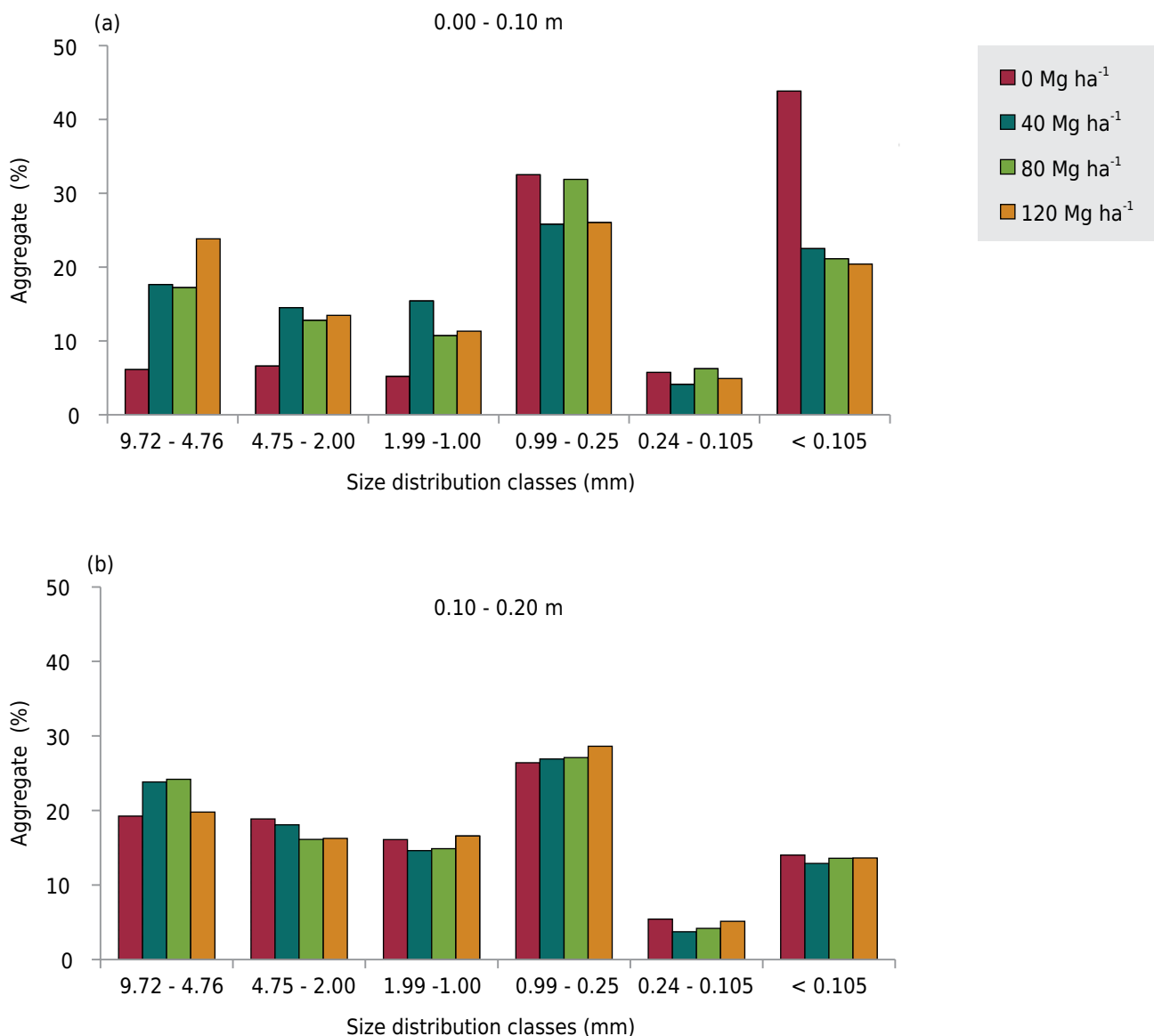

Figure 2. Distribution of water stable aggregates per size classes of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 (a) and 0.10-0.20 m (b) layers.

No effect of the RHA rate was noted on the θ_{CC} and θ_{PMP} values (Figures 4a and 4b) and AWC in both layers evaluated (Figure 5), possibly due to the short time period of the experiment. Similar results were obtained by Pauletto et al. (1990) in Brazil. However, several studies showed higher AWD using higher rates of fly ash (Ramesh et al., 2008; Ukwattage et al., 2013; Lu et al., 2014; Ram and Masto, 2014).

The S parameter, which represents the soil water retention curve slope at its inflexion point, was revealed as a sensitive indicator to evaluate the effects of RHA rates on the soil physical quality (Figure 6). The S values in the 0.00-0.10 m layer were above of the 0.035 set by Dexter (2004) as being favorable to the growth of plant roots. In the same layer, it was found that RHA increased S values, becoming stable at the 80 Mg ha^{-1}. This fact might be related to the increase in total porosity and macroporosity in this layer (Figures 1b and 1c). In the 0.10-0.20 m layer, S values were below that 0.035, indicating, in this case, an unsuitable distribution of pore sizes, according to Dexter (2004). Despite of S is a static parameter, therefore implicitly unable to describe dynamic processes (van Lier, 2014), we agreed that further studies can be carried out in this area including the relationship with different soil properties.

After normalizing the compressibility curves, in the 0.00-0.10 m (Figure 7a) and 0.10-0.20 m (Figure 7b) layers, only the first layer showed deformation of the soil structure with the maximum rate from 200 kPa.

Lower precompression stress values (σp) were obtained and a higher compressibility coefficient was found in the 0.00-0.10 m layer (Figures 8a and 8b), confirming the effects of RHA regarding the decrease in Bd (Figure 1a) and consequent increase in TP (Figure 1b) and Ma (Figure 1c). These values are classified as extremely high by Horn and Fleige (2003). However, similar values (Rucknagel et al., 2010; Vogelmann et al., 2012) and higher (Lima et al., 2004) σp have been found in other agricultural areas.
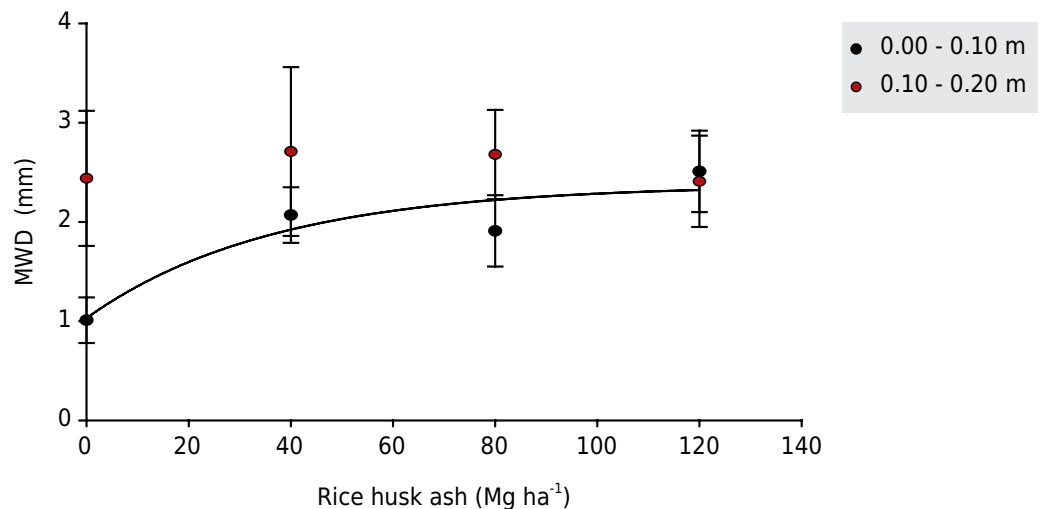

Figure 3. Mean weight diameter (MWD) of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 and 0.10-0.20 m layers.

Table 3. Coefficient of correlation (r) and probability (p) between the mean weight diameter (MWD) and the soil physical properties of a Typic Hapludult at the 0.00-0.10 and 0.10-0.20 m layers

		DC	Clay	Bd	TP	FD	OC
		0.00 – 0.10 m					
MWD	r	-0.02	0.46	-0.58	0.57	0.35	0.23
	p	0.924	0.009	<0.001	<0.001	0.030	0.134
		0.10 – 0.20 m					
MWD	r	-0.10	0.305	-0.297	0.256	0.436	0.56
	p	0.507	0.039	0.045	0.086	0.002	<0.001

DC: water dispersed clay; Bd: bulk density; TP: total porosity; FD: flocculation degree; OC: organic carbon.
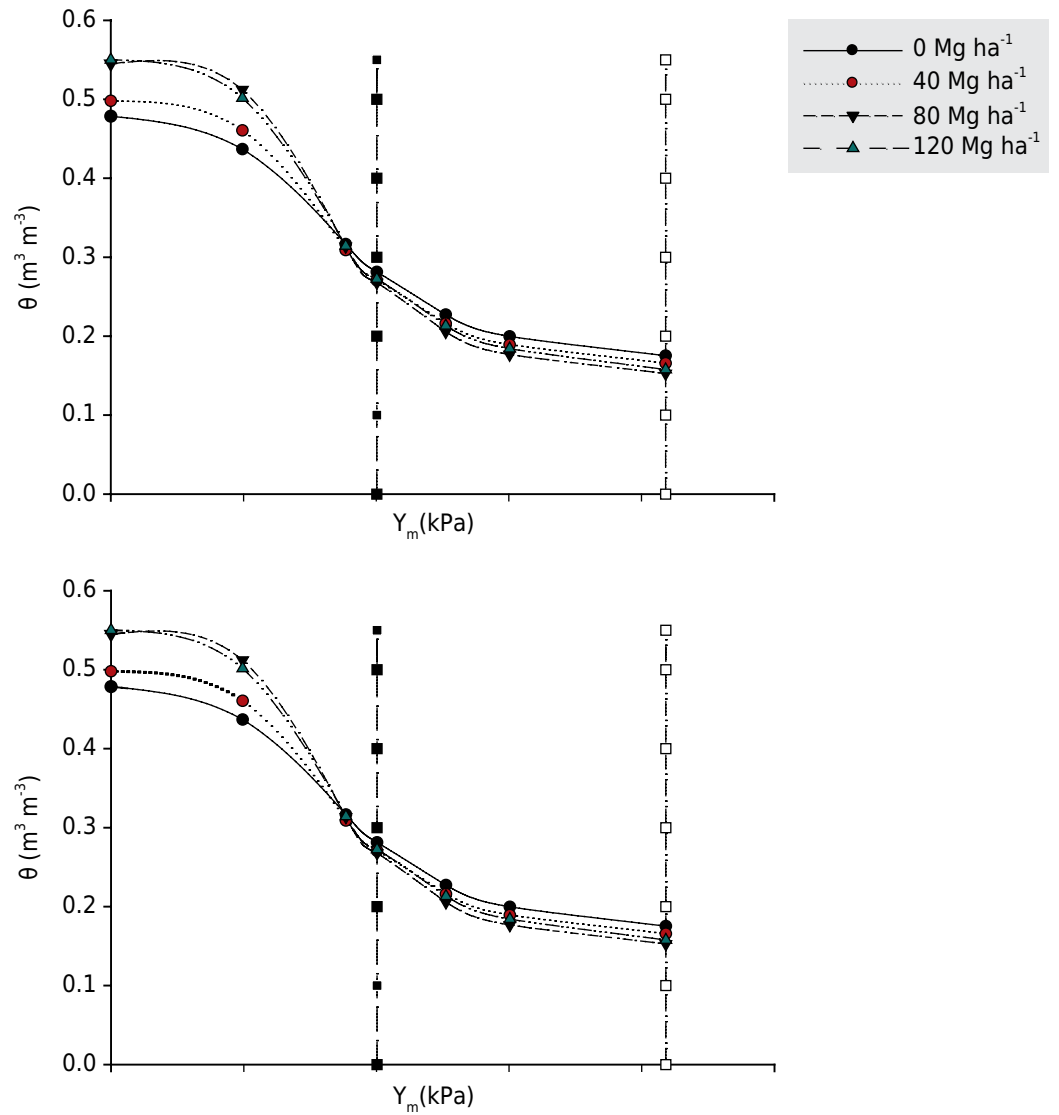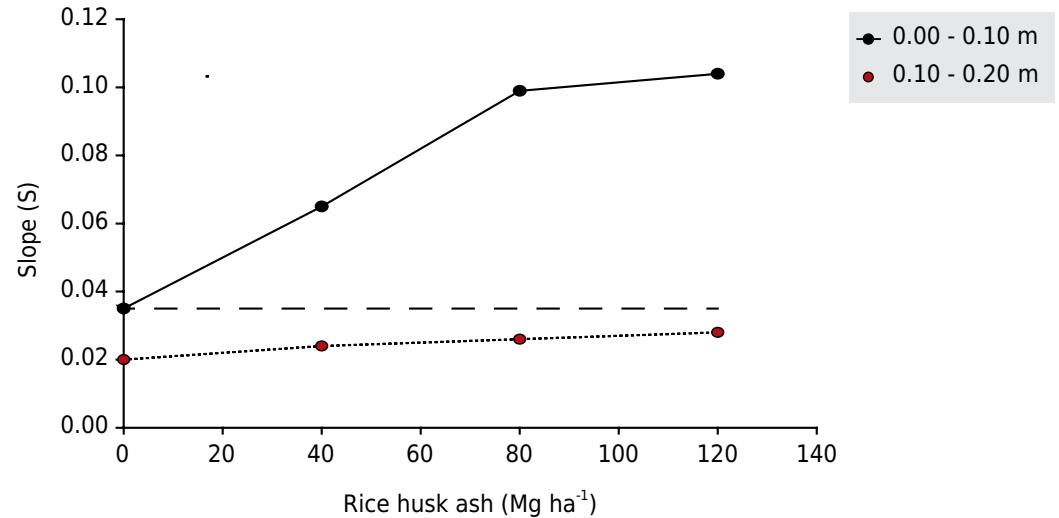
Figure 4. Water retention curves adjusted using the van Genutchen model of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 (a) and 0.10-0.20 m (b) layers. The vertical dotted lines indicated the θ_{CC} (soil water content at field capacity, 10 kPa) and θ_{PWP} (soil water content at wilting point, 1,500 kPa).
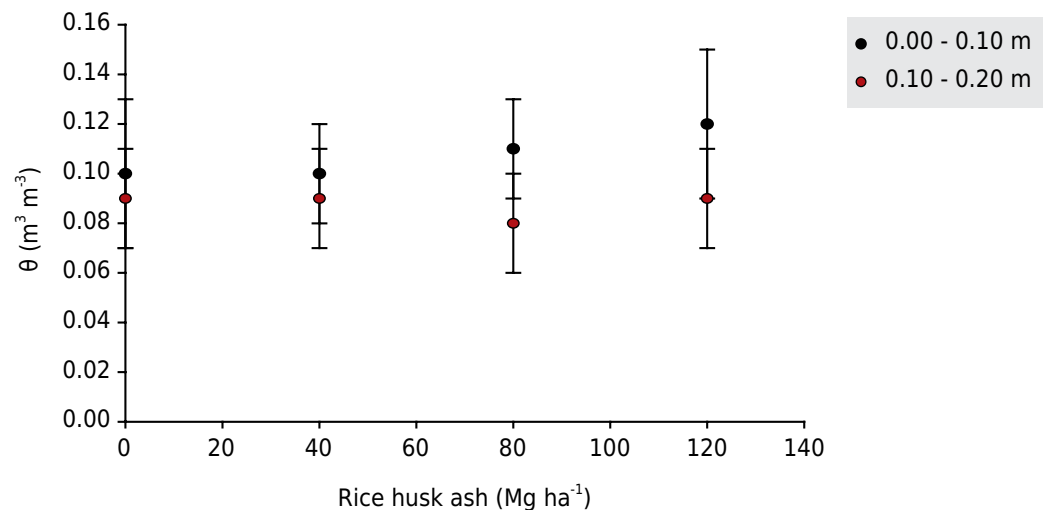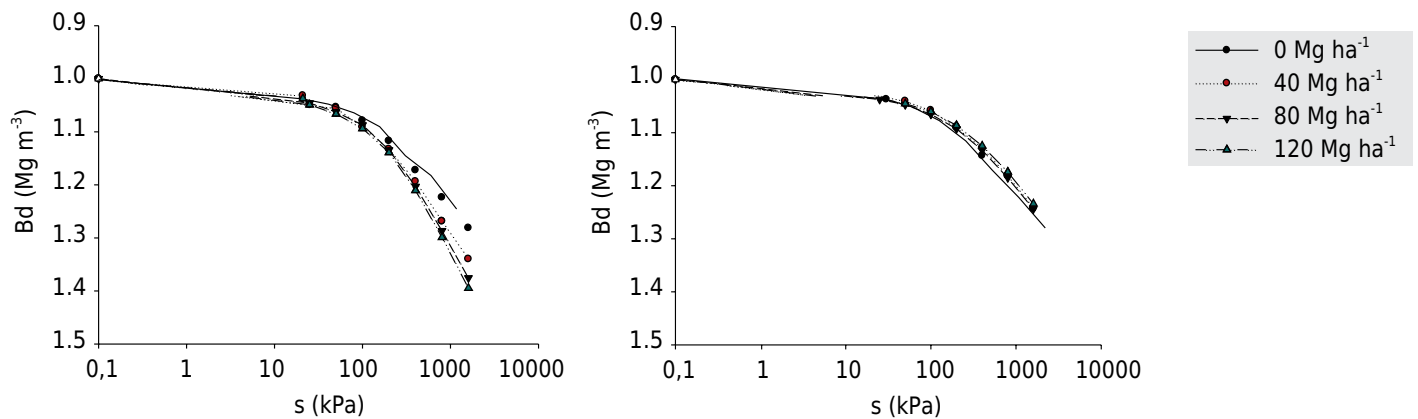

Figure 5. Available water capacity (AWC) of a Typic Hapludult under different rates of rice husk ash at the layers 0.00-0.10 and 0.10-0.20 m. Vertical bars indicate the standard deviation.

The parameters obtained from the uniaxial compression curve are relevant to the suitability of use practices, management and machine traffic, aiming to minimize soil degradation (Silva et al., 2002). The σp is related to the soil resistance to root penetration, and high values of precompression stress present a higher probability of reduced root growth (Pacheco and Cantalice, 2011).

Figure 6. S parameter of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 and 0.10-0.20 m layers. The dotted line indicates the critical value for crop.

Figure 7. Normalized compression curves of bulk density (Bd) versus applied loads of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 (a) and 0.10-0.20 m (b) layers.

$$\hat{y} = 0.35 + 9E\text{-}4\ x - 3.12E\text{-}1\ x^2$$
$$R^2 = 0.97$$
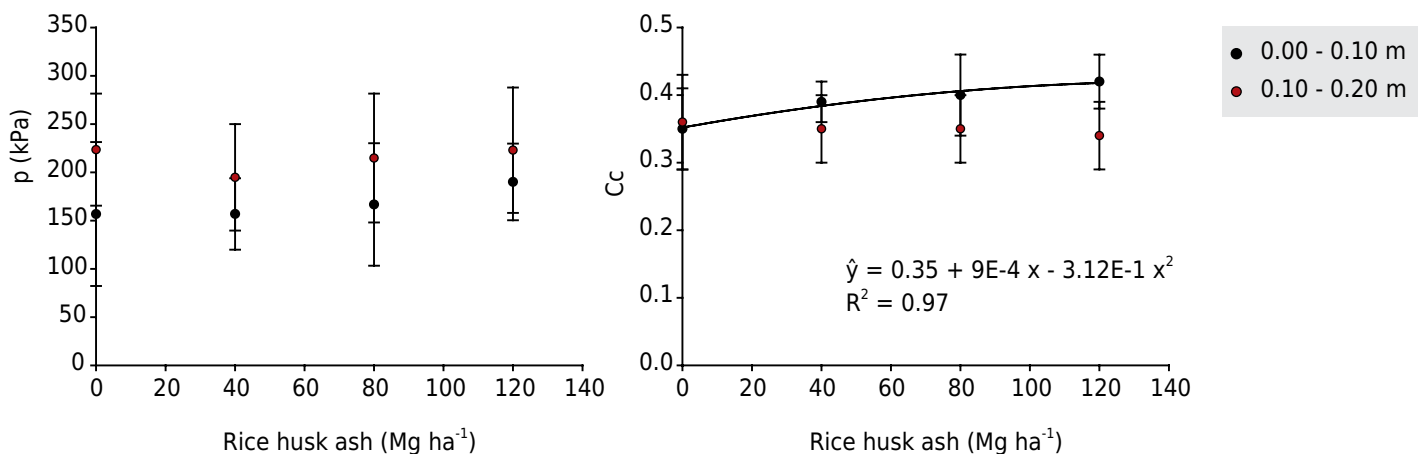
Figure 8. Precompression stress (σ_p) (a) and compressibility coefficient (Cc) (b) of a Typic Hapludult under different rates of rice husk ash in the 0.00-0.10 and 0.10-0.20 m layers. Vertical bars indicate the standard deviation.

The findings of this study might serve as a guide to the use of rice husk ash in soils similar to this. However, it is necessary to increase our knowledge on the physical and chemical mechanisms inherent to the observed effects.

CONCLUSIONS

Rice husk ash was shown to be an efficient residue to improve soil physical properties, mainly at rates between 40 and 80 Mg ha^{-1}.

Rice husk ash reduces bulk density and increases total porosity, macroporosity and soil aggregation, but does not affect microporosity, field capacity, permanent wilting point, and available water capacity of the soil.

The effect of rice husk ash on the S parameter, precompression stress and index compressibility coefficient values are consistent with those observed for the bulk density and total porosity.

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