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Effectiveness of sugarcane residue incorporation at different water contents and the Proctor compaction loads in reducing soil compactibility

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Abstract

Incorporation of crop residues into the soil can reduce its susceptibility to compaction. However, the significance of incorporated crop residue at different soil water contents at the time of compaction and the compaction loads is not well documented. The compactibility of three soils which contained different amounts of sugarcane residue was investigated at different water contents and compaction loads. The compaction loads were chosen to simulate the energy exerted by harvesters, trucks, vanguards, transporters and the standard Proctor test, respectively. A clay loam soil (Typic Ustochrepts), a clay soil (Typic Calciorthis), and a silty clay soil (Typic Torrifluvens) were thoroughly mixed with sugarcane residues of 0, 6.9 and 15.3 g per kg of soils, corresponding to 0, 27 and 60 Mg ha^{-1}, respectively. The sugarcane residue–soil mixtures were compacted using the standard Proctor procedure with different rammer drops, and dry bulk density was measured. The compaction was carried out at different soil water contents related to the consistency limits of the soils. Sugarcane residue was effective in reducing bulk density obtained with different compaction loads at different water contents. The optimum water content for maximum bulk density under compaction load of 551 J was obtained at 0.8 plastic limit (PL). For other compaction loads, however, the optimum moisture content was at PL. Results suggested that soil compatibility caused by heavy machinery of sugarcane production at water content lower than PL, can be reduced by incorporating 60 Mg ha^{-1} of sugarcane residue. Filed tests are required in order to verify the laboratory experimental data.

Keywords: Soil compaction; Sugarcane residue; The Proctor test; Soil water content

1. Introduction

In the Khuzestan province of Iran, the soils have been developed mainly from transported materials. They are generally medium to heavy textured with low organic matter content and poor structural stability. Agricultural practices with intensive machinery and low input of organic matter resulted in deterioration of soil structure leading to soil compaction.

Sugarcane (*Saccharum officinarum* L.) is a highly mechanised crop. Soil compactibility under sugarcane may arise during land preparation, planting, cultural practices and particularly harvesting operations. In Khuzestan province, there are about 43 000 ha under

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sugarcane and it will be increased to 100 000 ha by year 2003.

The susceptibility of soils under sugarcane to compaction depends not only upon the compressing loads by heavy machinery (Soane et al., 1982), but also upon the type of parent material, soil texture, moisture contents (Larson et al., 1980), organic matter (Soane, 1990), structural stability (Baumgart and Horn, 1991), and sodicity and salinity (Barzegar et al., 1996). Compaction reduces mainly the percentage of macropores and partly of mesopores (Soil Science Society of America, 1987), decreases the pore continuity, and increases horizontal orientation of soil pores (Frede, 1987; Pagliai, 1987). This may reduce soil available water (Kay, 1990), limit root growth (Dexter, 1987), and therefore reduce water and nutrient uptake by plants.

Numerous studies have indicated that crop residues such as wheat straw (Gue'rif, 1979), corn residue (Gupta et al., 1987), peatmoss (Ohu et al., 1985), and slightly and highly humified peats (Zhang et al., 1997) decrease soil compactibility. However, the influence of organic matter addition on soil compaction is not well documented. Particularly, information is scarce on interactions between organic matter, soil water content at the time of compaction and the compressing energy of agricultural machinery. Soane (1990) stated that the effect of organic matter is likely to be greater at high water content. Furthermore, a few researchers have used the standard Proctor test (e.g. Zhang et al., 1997) to evaluate soil compactibility. This method exerts a load which is higher than the compressing energy of agricultural machinery.

The objective of this study was to evaluate the changes in soil dry bulk density following sugarcane residue addition at different water contents and the Proctor compaction loads. The compaction loads were chosen to simulate the compressing energies exerted by sugarcane machinery.

2. Materials and methods

Three soil samples were collected from the top 0.3 m of long-term sugarcane plantations in Khuzestan, SW of Iran. The soils were from three sugarcane cultivation regions, viz. Haft-tapeh, a clay loam soil, Shoeibieh, a clay soil, and Amir-kabir, a silty clay. The soils had been under sugarcane for 36, 2 and 1 years, respectively.

Composite soil samples were analysed for physical and chemical properties. Organic matter content was determined by the dichromate oxidation method. Cation exchange capacity (CEC) was measured by a Na-saturation procedure. Electrical conductivity (EC) of saturation extract and pH of saturated paste of soils were measured. Gypsum and calcium carbonate contents were measured by acetone and titrometry procedures, respectively. Soil texture was determined by a pipette method (Gee and Bauder, 1986). Liquid (LL) and plastic (PL) limits were measured by methods outlined by ASTM (1992). Water contents of undisturbed soil cores were measured at the −33 and −1500 kPa matric potential using pressure plate apparatus. Chemical and physical characteristics of the soils are summarised in Table 1.

Sugarcane residue after harvesting was sampled at five random locations of 10 different sugarcane farms over a 4 m^2 area. The average sugarcane residue was 27 Mg ha^{-1} dry matter weight. The soil samples and

Table 1
Chemical and physical characteristics of soils used for the experiment[a]

Constituents	Region		
	Haft-tapeh	Shoeibieh	Amir-kabir
OM (g kg^{-1})	9.5	8.6	6.5
Carbonates (g kg^{-1})	426	418	496
Gypsum (meq/100 g)	3.4	4.1	2.3
Soluble cations (meq/l)			
Ca + Mg	10.5	11.0	10.0
Na	4.3	6.3	10.4
EC (dS m^{-1})	0.97	1.20	1.53
pH	7.1	7.4	7.5
CEC (cmol kg^{-1})	12.6	14.6	13.8
ESP	1.9	2.3	3.7
Clay (g kg^{-1})	350	480	440
Silt (g kg^{-1})	330	390	500
Sand (g kg^{-1})	320	130	60
Soil texture	Clay loam	Clay	Silty clay
$\theta_{m_{FC}}$ (g kg^{-1})	200	235	225
$\theta_{m_{PWP}}$ (g kg^{-1})	111	134	129
LL (g kg^{-1})	300	360	320
PL (g kg^{-1})	195	230	210

[a] OM, organic matter; EC, electrical conductivity; CEC, cation exchange capacity; ESP, exchangeable sodium percentage; FC, field capacity; PWP, permanent wilting point; LL, liquid limit; PL, plastic limit; θ, soil water content.

sugarcane residues were air dried and ground to pass a 2 mm screen and 10 mm screen, respectively. The ground/screened sugarcane residue was added to soils at rates of 0, 6.9 and 15.3 g dry weight matter of sugarcane residue per kg of soils. The amounts of residue corresponds to 0, 27 and 60 Mg ha^{-1} (depth of 0.3 m and bulk density of 1.3 Mg m^{-3}). The soil–residue mixtures were mixed thoroughly before being moistened with sprayed tap water. The standard Proctor test was applied at different water content to obtain the maximum dry density of the mixtures.

In the second part of experiment, the mixtures were moistened at three levels of water to reach, 0.4, 0.8 and 1 the plastic limits, PL. The samples were compacted by dropping a 2.5 kg rammer 75 times from a height of 30 cm corresponding to 551 J (the standard Proctor test). Three other compaction loads, of 44, 243 and 309 J, were used by dropping a 2.5 kg rammer 6, 33 and 42 times from a height of 30 cm, to simulate the three compaction loads, respectively. The compaction loads chosen corresponded to harvesters, trucks, vanguards and other transporters, respectively, used during sugarcane cultivation. The compressing energy of agricultural machinery depends upon weight and speed of machines, and upon the contact area of wheels with soils (Soane et al., 1980/1981). Therefore, the Proctor test which uses homogenised soils at constant energy input would differ from in situ soil compaction. The Proctor test, however, may be a good indicator of the sensitivity of soils to compaction in the field as used widely by civil engineers. In this study, the compressing energies exerted by harvesters, trucks and vanguards with known contact area and weight were calculated with results 309, 243 and 44 J, respectively. The dry bulk density was calculated from the soil mass in the Proctor cylinder and the water content that was measured after compaction. A complete factorial randomised design with four replicates was used to analyse the variance of soil properties such as bulk density, specific compaction energy, and soil water content data. Least significant difference (LSD) values were calculated to compare selected pairs of mean values at the 5 or 1% level of probabilities.

3. Results and discussion

The relationship between dry bulk density and water content of the soils at different levels of sugarcane residue is illustrated in Fig. 1 using the standard Proctor test. Analysis of variance of the data indicated that the effects of soil texture, sugarcane residue, water content, and the interactions of soil texture with either water content or sugarcane residue on dry bulk density were significant ($P < 0.01$). The optimum water content for the maximum dry bulk density increased as the clay content increased. Similar results

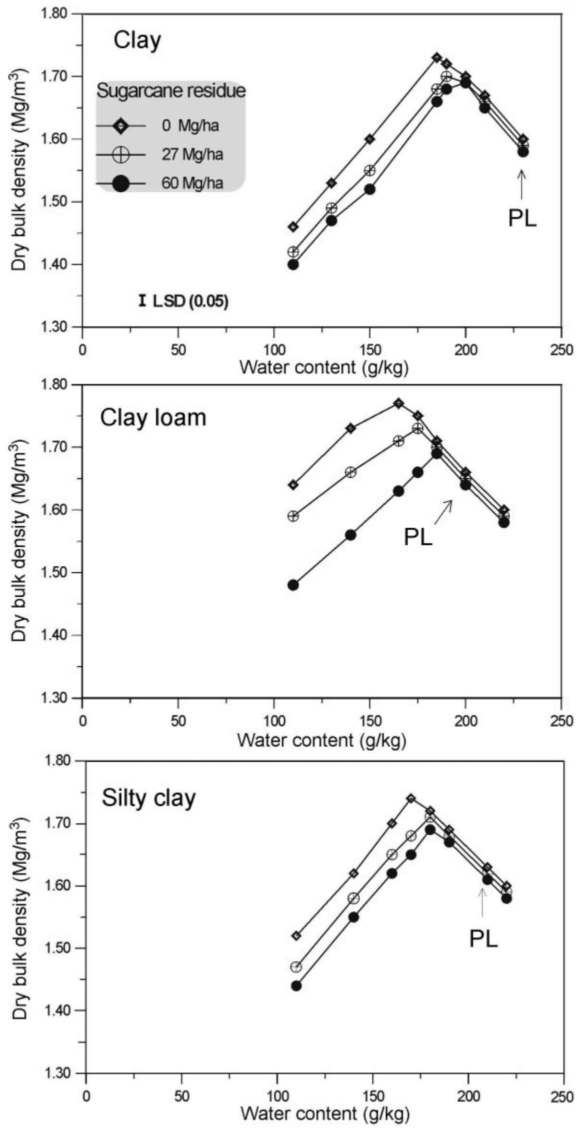

Fig. 1. Effects of water content and sugarcane residue on dry bulk density of soils using the standard Proctor test.

were reported by Larson et al. (1980) and Carig (1987).

The maximum dry bulk density with no residue added was below the PL and field capacity. The highest dry bulk density was achieved at 165, 185 and 175 g kg^{-1} soil water contents for clay loam, clay and silty clay soils, respectively, using a compaction load of 551 J. The maximum dry bulk density decreased with increasing sugarcane residue while the associated optimum water content increased. The effect was more pronounced at water content up to the optimum water content, particularly in clay loam soil compared to the other soils. The influence was small at high water content. It should be mentioned that the optimum water content is a good term from the civil engineering point of view but exactly the opposite one from the agricultural point of view. Overall, the results from three cohesive soils clearly

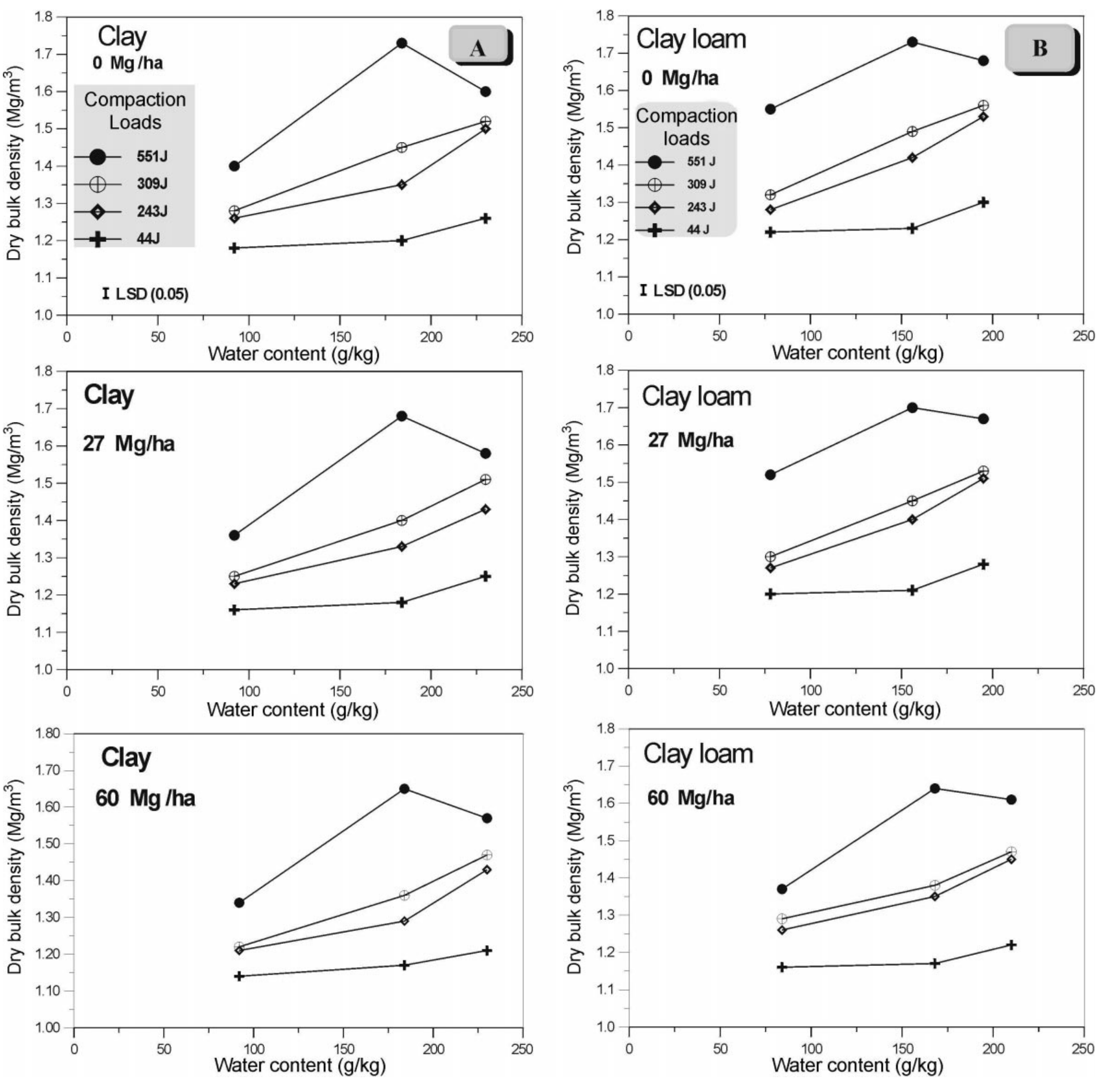

Fig. 2. Dry bulk density vs. water contents of soils at different compaction loads: A, clay soil; B, clay loam soil; C, silty clay soil. Subscripts 0, 27 and 60 refer to the amounts of incorporated sugarcane residue (Mg ha^{-1}).

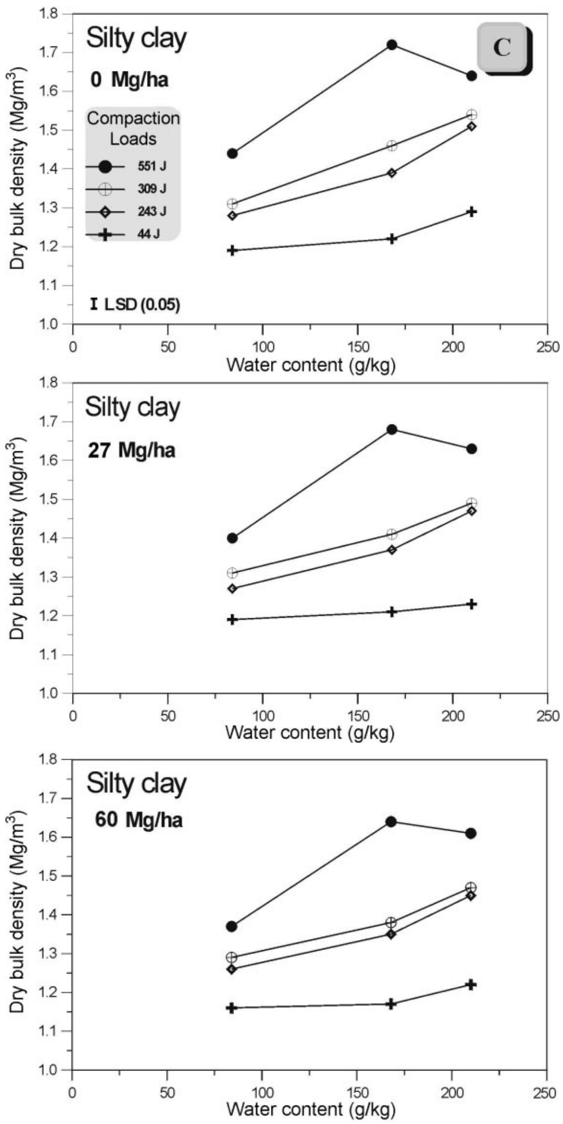

Fig. 2. (*Continued*).

indicated that sugarcane residue was most effective in reducing soil compactibility at moisture content less than PL. The water content had a more pronounced effect on dry bulk density than sugarcane residue particularly at water content higher than PL. This might be due to either a lubrication effect of water or because high water content reduces the elasticity behaviour of sugarcane residue. Organic matter due to high elasticity and low bulk density results in decreasing soil compactibility (Soane, 1990). After residue decomposition, organic matter increases soil structural stability (Oades, 1984; Dexter, 1988) and hence decreases soil compactibility (Baumgart and Horn, 1991; Barzegar et al., 1996).

The effectiveness of sugarcane residue in reducing soil compactibility at different water contents at different compaction loads is illustrated in Fig. 2.

Statistical analysis of the results showed that the effects of soil texture, sugarcane residue, moisture contents, compaction loads, and their interactions on dry bulk density were significant ($P < 0.01$).

At any particular water content and level of sugarcane residue, dry bulk density increased significantly with increases in the compaction loads. The maximum dry density for the standard Proctor test was measured at 0.8 PL. For other compaction loads, however, the maximum dry density was at PL. The influence of sugarcane residue in reducing soil compactibility using the standard Proctor test was significant ($P < 0.05$) at water content lower than 0.8 PL. For other compaction loads, the influence was significant ($P < 0.05$) at water contents of 0.4, 0.8 and 1 PL. This shows that the higher the compaction load, the lower is the range of water content for safe trafficking. Results indicated that the heavy machines used in sugarcane production may be used when soil moisture is below 0.8 PL and when sugarcane residue is mixed with soils.

Our results differ from those of Kuiper (1959) and Ohu et al. (1985). Kuiper (1959) indicated that the compressive strength of aggregates increased with increasing organic matter content at high water content ($pF = 1.9$) but not at low water content ($pF = 4.2$). Ohu et al. (1985) measured the penetration resistance of soils incorporated with different amounts of peat at different water content. They showed that the penetration resistance of compacted soils decreased with increasing peat content at low water content. At high water content, however, the penetration resistance increased with increasing peat contents. They attributed the increase in penetration resistance to high pore water suction of soils incorporated with peat.

The results presented here, confirmed the conclusion drawn by Zhang et al. (1997). They showed the effectiveness of organic matter at low water content (less than the optimum water content for maximum dry bulk density). They also suggested that the dry bulk density as an appropriate measurement to asses soil compactibility following organic matter incorporation.

At water content lower than PL, the elasticity behaviour of sugarcane residue was high and therefore sugarcane residue was more effective in reducing soil compactibility compared to water content higher than PL. However, at high water content nearly all pores were saturated with water and the elasticity behaviour of sugarcane residue was low.

In this experiment, we investigated the effect of sugarcane residue on soil compactibility using different compaction loads. Roots of sugarcane are mainly distributed in the top soil (Torres et al., 1990). Compaction of top soil can be reduced by residue incorporation. Subsoil compaction is also of great importance for sugarcane production. Furthermore, Zhang et al. (1997) indicated that highly humified peat reduced soil compatibility more than slightly humified peat. How the decomposed sugarcane residue reduces soil compactibility has to be investigated.

4. Conclusions

Increasing compaction loads increased the sensitivity of soils to compaction. Sugarcane residue was effective in reducing compactibility of cohesive soils at water content lower than 0.8 PL for the standard Proctor test. Sugarcane residue at the rate of 27 and 60 Mg ha^{-1} also reduced the soil compactibility induced by different Proctor compaction loads at water content lower than PL.

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