*Int. Agrophysics, 2005, 19, 345-350*

INTERNATIONAL
**Agrophysics**
www.ipan.lublin.pl/int-agrophysics

# Effect of organic carbon content on the compactibility and penetration resistance of two soils formed from loess

*S. Tarkiewicz* and A. Nosalewicz*

Institute of Agrophysics, Polish Academy of Science, Doświadczalna 4, P.O. Box 201, 20-290 Lublin 27, Poland

*Received October 19, 2004; accepted March 30, 2005*

A b s t r a c t. Penetration resistance and bulk density were measured in the laboratory for two soils: grey-brown and brown, both formed from loess with different $C_{org.}$ content which had been compacted using the Proctor test. The compaction was carried out at different moisture content of the soils. Values of bulk density and penetration resistance of the soils increased with increased moisture content up to maximal values after which the values decreased with further increments in moisture content. Increased content of $C_{org.}$ caused a decrease of compactibility of the investigated soils and a decrease of their penetration resistance in dependence on their moisture content and bulk density. Maximum values of penetration resistance decreased and the corresponding moisture content increased with increasing $C_{org.}$ content in both soils formed from loess. $C_{org.}$ content in analyzed soils had a great effect on the relation between penetration resistance and soil moisture and its bulk density.

K e y w o r d s: soil compactibility, $C_{org.}$ content, penetration resistance, bulk density

## INTRODUCTION

About 20% of total soil degradation in the world can be defined as induced by soil compaction, while even only in Europe about 33 Mha of arable land are already completely devastated by non-site-specific wheeling and tillage processes (Soane and van Ouwerkerk, 1994).

In Poland soil compaction has become one of the main factors influencing the physical state of soils and, in consequence, the plant production (Lipiec *et al*., 1999). Intensive tillage of soils causes also a decrease of the content of $C_{org.}$, which has an essential influence on the susceptibility of the soils to compaction (Józefaciuk *et al*., 2001; Oades, 1984).

The Proctor test (Proctor, 1933) is the method most often used by researchers to determine soil compactibility basing on critical soil moisture – moisture needed to reach maximum soil bulk density. Maximum of soil bulk density depends on load, time of load, soil water content, mechanical composition, and $C_{org.}$ content. Soil bulk density and soil penetration resistance are the most often used indicators of soil compaction and they can be used in a wide range of soil moisture (Ohu *et al*., 1985; Schjonning, 1991). Soane (1975) on the basis of 58 soils of Scotland (with differentiated grain size distribution and $C_{org.}$ content) showed a close relationship between the maximum bulk density of soil as obtained with the Proctor test and the $C_{org.}$ content. Increase in the $C_{org.}$ content of the soils under study resulted in a decrease in the value of maximum bulk density and therefore also in the susceptibility of the soils to compaction.

Decrease of soil compactibility is observed after mixing soil with organic matter (peat, manure, straws, *etc*.), either as a result of direct mixing of soil with organic matter that has lower bulk density, or, indirectly by affecting the stability of soil aggregates (Ekwue and Stone, 1993; 1995; 1997). Zhang *et al.* (1997) indicated that highly humified peat reduced soil compactibility more than slightly humified peat. Also the incorporation of crop residues into the soil can reduce it susceptibility to compaction (Barzegar *et al*., 2000). Increase of the amount of water molecules around soil particles with high content of organic matter helps in decreasing soil compaction (Soane, 1990).

Ekwue and Stone (1995) found that the effect of organic matter on strength properties (estimated by soil penetration resistance and shear strength) of compacted agricultural soils depends on the level of moisture content at compaction and on the type of organic matter. Organic matter reduces soil strength at low moisture levels and increases it at high moisture content. Within a given soil type, the penetration resistance depends on the bulk bulk density, water content,

*Corresponding author's e-mail: tarkiew@demeter.ipan.lublin.pl

and on the structure of the soil. Ohu *et al.* (1985) showed that the penetration resistance of compacted soils decreased with increasing peat content at low water content. They attributed the increase in penetration resistance to high water potential of soils incorporated with peat.

Studies mentioned above concerned the effect of the addition of various types of organic matter to different soil types on its compatibility and strength (estimated by soil penetration resistance), and the relationship between the maximum bulk density and the $C_{org.}$ content in soils with different grain size distributions.

The aim of this study is to determine the effect of $C_{org.}$ content in soils formed from loess with similar granulometric composition on soil compactibility and penetration resistance and on the relation between $C_{org.}$ content and soil bulk density on penetration resistance at various water content.

## MATERIAL AND METHODS

The soils used in this study were grey-brown and brown, both formed from loess, representing some of the major agricultural soil in the Lublin region (Table 1). The soil samples were collected from the depth of 0-20 and 20-135 cm of the soils profile. Soil samples were taken from two depths; they have similar mechanical composition but they differ in their $C_{org.}$ content (Table 1).

The organic carbon content was determined by Tiurin's method.

The standard Proctor test (Proctor, 1933) was applied to determine the influence of moisture content on the value of bulk density as a function of load and to quantify the soils compactibility.

Soil samples were prepared for measurements as recommended for Proctor tests. Air-dry soil samples weighing about 20 kg were sieved with 6.35 x 6.35 mm mesh. Sieved soils were used to prepare 6-7 samples weighing 2.5-3 kg each, the volume of every sample was 1 $dm^3$. Distilled water was added to each sample to reach specified water content of soil sample. Soil samples moisture content varied from 3 to 29%, mass. Soil samples were compacted in 112.8 mm inner diameter and 100 mm height cylinders in 3 equal layers. Each soil layer was compacted by 25 blows of a 2.5 kg hammer falling from 320 mm height. Soil bulk density and moisture were measured after the compaction.

Bulk densities were plotted against the corresponding moisture content to obtain maximum bulk bulk density and critical moisture content. The penetration resistance of the compacted soil in the cylinder at the given moisture content and bulk density of soil was conducted using an INSTRON apparatus. Measurement of penetration resistance was carried out (in three replications per cylinder) with a probe 110 mm long, with a cone tip of 4.6 mm and a cone angle of 30°. For each cylinder with compacted soil was determined the mean value of penetration resistance at 20-60 mm depth since at that range of profile depth the results of the measurements were not affected by the surface conditions of the soil.

The results of measurements presenting the relation between soil bulk density and soil moisture samples allowed for the calculation of critical moisture at which soil achieved maximum bulk density. Soil compactibility as a function of $C_{org.}$ content in the sample was estimated in the second step. Relation between soil penetration resistance and soil moisture at various $C_{org.}$ content was calculated as a result of the measurement. Least square method (Statistica 6.0) was used to elaboration of dates.

## RESULTS AND DISCUSSSION

### Soils compactibility

The relations between soil moisture and bulk density of analyzed soil samples with different $C_{org.}$ content are presented in Figs 1 and 2. Values of bulk density of the soils increased with moisture content up to maximal values after which the values decreased with further increments in moisture content. Organic carbon content had a large effect on the relation between these two properties for both kinds of soils. Soil bulk density was lower for both soils from top 0-20 cm layers than from deeper layers as a result of higher $C_{org.}$ content.

The moisture content at which maximum bulk density occurs is called 'optimum' in engineering work. This is, however, called 'critical' in this article because in agricultural practice, soil compaction is an undesirable phenomenon and the moisture content at which its maximum occurs should be called 'critical' not 'optimum'.

**T a b l e 1.** Granulometric composition and $C_{org.}$ content in investigated soils

| Soils formed from loess | Depth (cm) | Granulometric composition (%, dia in mm) | | | | $C_{org.}$ (%) |
|---|---|---|---|---|---|---|
| | | 1-0.1 | 0.1-0.02 | <0.02 | <0.002 | |
| Grey-brown | 0-20 | 1 | 63 | 36 | 9 | 2.1 |
| (Zagrody) | 75-130 | 1 | 58 | 41 | 9 | 0.2 |
| Brown | 0-20 | 1 | 51 | 48 | 15 | 1.68 |
| (Skierbieszów) | 20-90 | 1 | 49 | 50 | 20 | 0.3 |

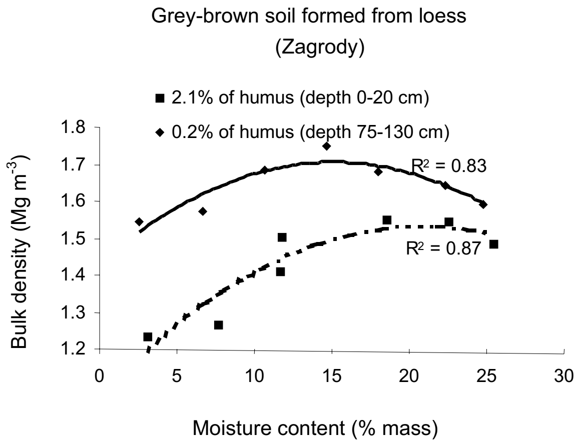


**Fig. 1.** Relation between bulk density and moisture content at different $C_{org.}$ content in grey-brown soil formed from loess.

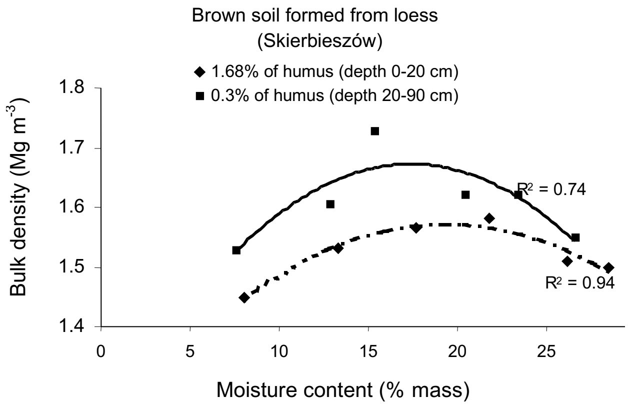


**Fig. 2.** Relation between bulk density and moisture content at different $C_{org.}$ content in brown soil formed from loess.

**T a b l e 2.** Maximum bulk density and the corresponding critical moisture content of the soils with different $C_{org.}$ content

| Soils formed from loess | $C_{org.}$ content (%) | Critical moisture content ($W_{crit}$) (% mass) | Maximum bulk density (MD) (Mg m$^{-3}$) |
|---|---|---|---|
| Grey-brown | 2.1 | 18.5 | 1.549 |
| (Zagrody) | 0.2 | 14.7 | 1.751 |
| Brown | 1.68 | 21.8 | 1.582 |
| (Skierbieszów) | 0.3 | 15.3 | 1.727 |

Values of critical moisture ($W_{crit.}$) at which soils with higher $C_{org.}$ content reached maximum bulk densities were about 4% lower as compared to soil samples with lower $C_{org.}$ content (Table 2).

Maximum bulk density of the grey-brown soil with $C_{org.}$ content of 2.1% at critical soil moisture of 18.5% was 1.55 Mg m$^{-3}$, at 0.2% $C_{org.}$ content and corresponding critical moisture of 14.7% it reached 1.75 Mg m$^{-3}$. Similar relation can be observed for brown soil, at 1.68% organic carbon content, the critical moisture was 21.8%, maximum bulk density 1.582 Mg m$^{-3}$, for the same soil but at lower organic carbon content: 0.3%, critical moisture was 15.3% and maximum bulk density was 1.73 Mg m$^{-3}$ (Table 2). Maximum soil bulk density was clearly lower for soils with high $C_{org.}$ content.

Presented results indicate the important effect of $C_{org.}$ content both on grey-brown and brown soils formed from loess on their compactibility. Increase of the value of critical moisture content at which soils reached maximum bulk density and lower values of maximum soil bulk density were observed with increase of $C_{org.}$ content. Reduced soil compatibility at higher $C_{org.}$ content could be an effect of increase in resistance to deformation and increase in elasticity (Soane, 1990).

PENETRATION RESISTANCE OF SOILS

The values for main effects of $C_{org.}$ content on penetration resistance and the corresponding moisture content at which maximal values occurred are shown in Table 3.

Values of penetration resistance of the soils increased with increments in moisture content up to maximal values after which the values decreased with further increments in moisture content. $C_{org.}$ content had a large effect on the relation between these two properties and bulk density for both types of soils (Figs 3A, B and 4A, B).

Maximum penetration resistance ($PR_{max}$) of the grey-brown soil with $C_{org.}$ content of 2.1% at corresponding moisture content of 11.7% was 6 MPa, while the penetration resistance reached 9.9 MPa at the 0.2 $C_{org.}$ content and corresponding moisture content of 9% (Table 3). Similar relation can be observed for brown soil. At the 1.68% $C_{org.}$ content the maximum penetration resistance was 7.1 MPa at a moisture content of 8.7%, while for the same soil but at a lower $C_{org.}$ content of 0.3% maximum penetration resistance was 11.6 MPa at corresponding moisture content of 7.6%. It will be noted from Table 3 that while maximum penetration resistance decreased, the corresponding moisture content increased with increasing $C_{org.}$ content in both

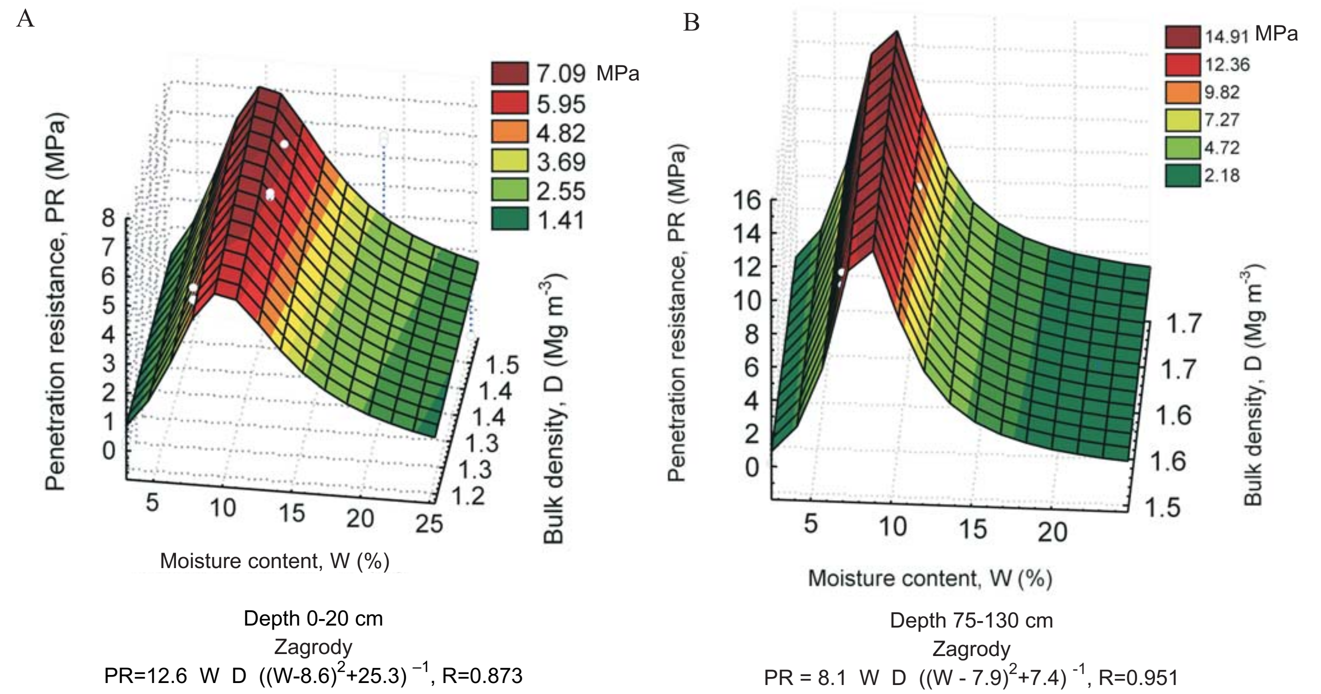


**Fig. 3.** Relation between penetration resistance (PR), moisture content (W), and bulk bulk density (D), in grey-brown soil formed from loess: A) 2.1% and B) 0.2% of $C_{org.}$ content. Legend presents penetration resistance values (MPa).

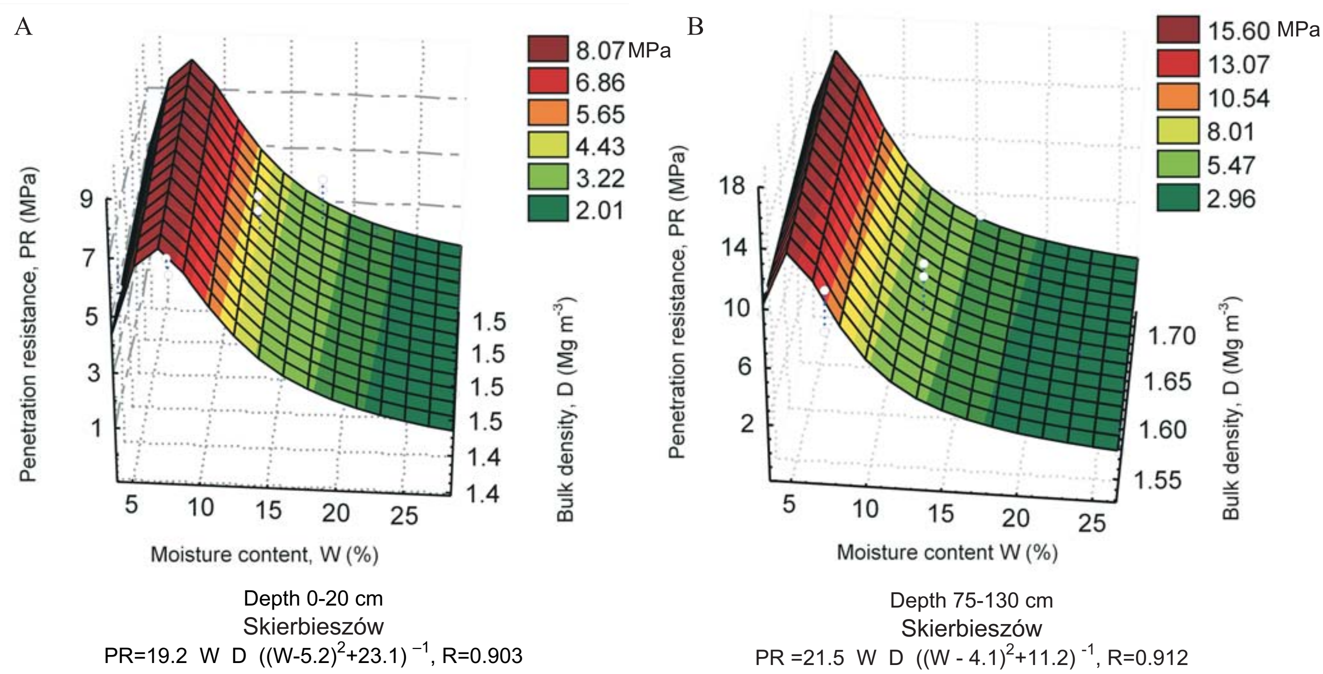


**Fig. 4.** Relation between penetration resistance (PR), moisture content (W), and bulk density (D), in grey-brown soil formed from loess: A) 2.1% and B) 0.2% of $C_{org.}$ content. Legend presents penetration resistance values (MPa).

**T a b l e 3.** Maximum penetration resistance ($PR_{max}$) and the corresponding critical moisture content ($W_{crit.}$) values of the soils with different humus content

| Soils formed from loess | $C_{org.}$ content (%) | $W_{crit.}$ (% mass) | $PR_{max}$ (MPa) at $W_{crit.}$ |
|---|---|---|---|
| Grey-brown | 2.1 | 11.7 | 6.0 |
| (Zagrody) | 0.2 | 6.7 | 9.9 |
| Brown | 1.68 | 8.0 | 7.1 |
| (Skierbieszów) | 0.3 | 7.6 | 11.6 |

soils. Ekwue and Stone (1995) in their investigations affirmed that the moisture content at the measured maximum penetration resistance increases with increasing added organic matter because organic materials increased the consistency limits of the soils. The increases in consistency limits of soils with organic matter occurred because $C_{org.}$ content makes the first demand on water added to soils.

Relation between soil penetration resistance, soil moisture and bulk bulk density for the investigated soils can be described as:

$$PR= a\ W\ D\ ((W-b)^{2}+c)^{-1}$$

where: a, b, c – least square method calculated coefficients; PR – penetration resistance (MPa); D – soil bulk density (Mg $m^{-3}$); W – soil moisture (% mass).

This function was chosen because of:

– observed maximum of soil penetration resistance as a function of soil moisture and ease of calculation of soil moisture value at this point;
– assumption of linear relation between soil penetration resistance and its bulk density;
– relatively small amount of measured points and an intention to estimate the relation in a wider range of parameters;
– relative simplicity of the equation which meets the assumption mentioned above and fits well the measured points.

Figures 3A, B and 4A, B show measured points and fitted function PR (W, D). Calculated coefficients of correlation confirm that chosen function fits well the measured points. $C_{org.}$ content in analyzed soils has a great effect on relation between soil penetration resistance and soil moisture and its bulk density. Penetration resistance of both soils with higher content of $C_{org.}$ is much lower than of soils with lower $C_{org.}$ content at the same moisture content.

The results from this study suggest that in soils with similar texture and different content of $C_{org.}$ the values of penetration resistance depend not only on moisture content and bulk bulk density but also on the $C_{org.}$ content.

## CONCLUSIONS

1. Organic carbon content in the investigated soils had a great effect on compactibility and values of penetration resistance of the investigated soils.

2. Increase of $C_{org.}$ content caused a decrease of compactibility of the investigated soils. Increase of value of critical moisture content at which soils reached maximum bulk density and lower values of maximum soil bulk density were observed with increase of $C_{org.}$ content.

3. Maximum values of penetration resistance decreased and the corresponding moisture content increased with increasing $C_{org.}$ content in both soils formed from loess.

4. Penetration resistance of both soils with higher content of $C_{org.}$ was much lower than in samples with lower $C_{org.}$ content at the same moisture content.

## REFERENCES

**Barzegar A.R., Assodar M.A., and Ansari M., 2000.** Effectiveness of sugarcane residue incorporation at different water contents and the Proctor compaction loads in reducting soil compactibility. Soil Till. Res., 57, 167-172.

**Ekwue E.I. and Stone J.R., 1993.** Maximum bulk density achieved during soil compaction as affected by the incorporation of three organic materials. Transactions of the ASAE, 36, 6, 1713-1719.

**Ekwue E.I. and Stone R.J., 1995.** Organic matter effects on the strength properties of compaction agricultural silos. Transactions of the ASAE, 38, 2, 337-365.

**Ekwue E.I. and Stone J.R., 1997.** Density-moisture relations of some Trinidadian soils incorporated with sewage sludge. Transactions of the ASAE, 40, 2, 317-323.

**Józefaciuk G., Muranyi A., Szatanik-Kloc A., Farkas C., and Gyuricza C., 2001.** Change of surface, fine pore and variable charge properties of a brown forest soil under various tillage practices. Soil Till. Res., 59, 127-135.

**Lipiec J., Pabin J., and Tarkiewicz S., 1999.** Soil compaction in Poland: assessment and effects. In: Experiences with the Impact and Prevention of Subsoil Compaction in the European Community (Eds J.J.H. van den Akker, J. Arvidsson, R. Horn). DLO-Staring Centre,Wageningen, The Netherlands, 180-195.

**Oades J.M., 1984.** Soil organic matter and structural stability mechanics and implications for management. Plant Soil, 76, 319-337.

**Ohu J.O., Raghavan G.S.V., and McKyes E., 1985.** Peatmoss effect on the physical and hydraulic characteristic of compacted soils. Transactions of the ASAE, 28(5), 420-424.

**Proctor R.R., 1933.** Fundamental principles of soil compaction. Description of field nad laboratory methods. Eng. News Record, 111, 286-289.

**Schjonning P., 1991.** Soil strength as influenced by texture, water content and soil management. Proc. 12th Conf. ISTRO, Ibadan, Nigeria, 277-283.

**Soane B.D., 1975.** Studies of some soil physical properties in relation to cultivations and traffic. In: Soil Physical Conditions and Crop Production. Min. Agric. Fish. Food, Tech. Bull., 29, HMSO, London.

**Soane B.D., 1990.** The role of organic matter in soil compactibility: a review of some practical aspects. Soil Till. Res., 16, 1-2, 179-201.

**Soane B.D. and van Ouwerkerk C., 1994**. Soil compaction in crop production. In: Conclusions and Recommendations for Futher Research on Soil Compaction in Crop Production. Chapter 26, Elsevier, Amsterdam.

**Zhang H., Hartge K.H., and Ringe H., 1997.** Effectiveness of organic matter incorporation in reducing soil compactibility. Soil Sci. Soc. Am. J., 61, 239-245.