EVALUATING THE SUSTAINABILITY OF DIFFERENT SOIL TILLAGE PRACTICES USING FIELD MEASURED ELECTRICAL PROPERTIES

Csilla FARKAS[1] – Antti RISTOLAINEN[2] – Tibor TÓTH[1] – Sándor KOÓS[1] – Péter LÁSZLÓ[1]

[1]Research Institute for Soil Science and Agricultural Chemistry of the HAS, Budapest, Hungary; [2]MTT Agrifood Research, Jokioinen, Finland

Introduction

Sustainable and soil conserving utilization of soils require knowledge of soil physical, chemical and biological properties affecting soil water, heat and nutrition regime. In Hungary soil moisture control - prevention, elimination or moderation of extreme moisture situations - is essential for sustainable land use and site-specific soil management (*Várallyay*, 2004). Soil tillage may play an important role in these actions (*Soane & Ouwerkerk*, 1994), especially under rainfed conditions, as in Hungary. Soils under tillage, however, have been found to be generally less stable than those under forest or grassland (*Low*, 1972). Soil physical degradation, reflected by changes in the shape of the soil water retention curve has harmful effects on soil water regime and on aeration (*Štekauerová et al.* 2006). When soil is degraded, the value of the soil water content at saturation becomes smaller and the slope of the retention curve at the inflection point, S also becomes smaller (*Dexter*, 2004). S has been found to be a useful measure of soil physical quality (Birkás et al., 2006).

Soil properties vary strongly in space and time, thus, their determination is costly and time consuming. The need for more detailed information on spatial and temporal variation of soil properties (e.g. for precision agricultural utilisation) (*Jolánkai & Németh*, 2002) lead to increasing interest over indirect methods for mapping soil properties. These methods allow overcoming the costs of detailed soil mapping based on traditional sampling. In-situ measurement of bulk soil electrical conductivity (ECa) is a quick and relatively easy method. The instrument readings show correlation with a number of soil properties that affect yield potential and environmental factors. This is why ECa measurements have been seen as one of the most promising methods. Several investigations have been carried out to study the relationship between the field measured ECa values (indirect measurements) and soil water, salt and humus contents, pH, mechanical composition and other soil properties. However, the relationship between data, obtained by indirect measurement techniques and soil hydraulic properties and soil quality indicators has not been widely examined yet.

This paper studies the relationship between certain soil hydraulic properties, the soil quality indicator S and data, obtained from indirect field measurements in a long-term tillage experiment.

Material and methods

The investigation was carried out at the Hatvan experimental station, located 60 km north-east from Budapest on the northern edge of the Carpathian basin. The soil is a chernozem, developed on loam. A long-term tillage experiment was set up in 2002 on 13 x 150 m experimental plots with four replicates in a split-plot design. The tillage variants

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comprised mouldboard ploughing (P, 0.26-0.30 m); disking (D, 0.16-0.20 m); loosening + disking (L+D, L: 0.40-0.45 m, D: 0.16-0.20 m), two cultivator treatments (C, 0.16-0.20 m and FC, 0.12-0.16 m) and direct drilling (DD) (*Birkás & Gyuricza,* 2004). The crop sequence – wheat-maize - was improved by catch crops (mustard, rye, pea).
In April 2005, indirect field measurements were performed using a Four electrode resistivity sensor (Conductivity fork, *Puranen et al.,* 1999, CF_EC), capacitive probe 'Percometer' (Adek ltd, Estonia, P_EC) and a capacitive probe (BR-30, RISSAC, Hungary, 0.10 m). The Four electrode resistivity sensor shows electrical conductivity readings (CF_EC) (*Puranen et al.,* 1999). Soil water content (WC) and permittivity (PERR) were measured with the BR-30 instrument and the Percometer. Percometer measures only small soil volume (point measurement) and measurements were taken at the depth of 0.2 m. Field measurements were performed at 13 points of 24 transects (=312 points), having 4 transects in each of the six tillage treatments. The distance between transects and measurement points were 4 m and 7 m, respectively.
Parallel to the field measurements, disturbed (0-0.2 m layer) and 10^{-4} m^3 volume undisturbed (0. 15-0.20 m layer) soil samples were collected from 12 locations of each tillage treatment. From the undisturbed soil cores, bulk density (BD) and soil water retention characteristics were measured at water potentials of -1, -2.5, -10, -32 -100, -200, -500, -2500 and -15850 hPa. The Van-Genuchten model was fit to the experimental soil water retention data. Soil water content at the inflection point (WC_infl) and soil quality indicator S were calculated according to *Dexter* (2004) using the parameters (WSC – soil water content at saturation (WC(pF=1)), WRC – residual soil water content (WC(pF=4.2)) and fitting parameters n, m and alpha) of the Van-Genuchten analytical expression. From the disturbed soil samples soil texture, pH, plasticity index (Ka), salt content (SC), organic matter content (OM), electrical conductivity (EC) and particle density (PD) were determined.
Analyses of variance were performed. Determination coefficients (R^2) between the instrument readings P_EC, FC_EC, PERR and BR and the measured soil properties were calculated for the whole dataset (n=72) and separately for each tillage treatment (n=12).

Results and discussions
According to the ANOVA results (Table 1), the experimental site was homogeneous in soil chemical properties and texture. P was the only outstanding treatment, probably because of the intensive mixture of soil layers up to 0.3 m depth. Still, statistically significant differences between the instrumental readings were found (Table 2).

Table 1. Mean (n=12) values of soil properties, measured in different tillage treatments

	pH (H_2O)		**SC (%)**		**HUM (%)**		**Sand (%)**		**Clay (%)**	
D	6.06	a	0.01	a	3.36	a	6.8	a	34.4	a
DD	6.04	a	0.02	ab	3.40	a	6.2	a	34.5	a
C	6.06	a	0.02	ab	3.43	a	5.5	a	34.2	a
L+D	6.04	a	0.02	ab	3.37	a	5.5	a	34.5	a
FC	6.09	a	0.01	a	3.45	a	5.7	a	33.3	b
P	6.19	a	0.03	b	3.42	a	8.7	b	33.9	ab

Values are statistically significantly ($p < 0.05$) if the same letters do not follow them.

In our previous study, carried out in the Apaj region along three 70 m long transects (*Ristolainen et al.*, 2006, *Tóth et al.*, 2006), variation in field measured EC values reflected differences in land use (pasture, maize, forest, wheat) systems and soil types along a salt-affected grassland. In the case of the Hatvan tillage experiment differences in instrument readings were most probably related to changes in soil properties, caused by different tillage systems. Thus, regardless to small spatial variability of topsoil texture and chemical properties, the tillage treatments could be clearly distinguished.

Table 2. Mean (n=52) values of indirect measurements in different tillage treatments

	CF_EC		**P_EC**		**PERR**		**BR-WC**	
D	28.2	ab	32.5	ab	36.0	a	46.6	a
DD	28.7	c	32.8	b	36.1	a	47.0	a
C	27.6	ab	33.7	bc	36.0	a	45.3	b
L+D	25.9	bd	30.9	ab	36.2	a	44.6	b
FC	31.8	c	35.1	c	36.5	a	46.7	a
P	25.3	d	30.3	a	33.0	b	42.4	c

Values are statistically significantly ($p < 0.05$) if the same letters do not follow them.

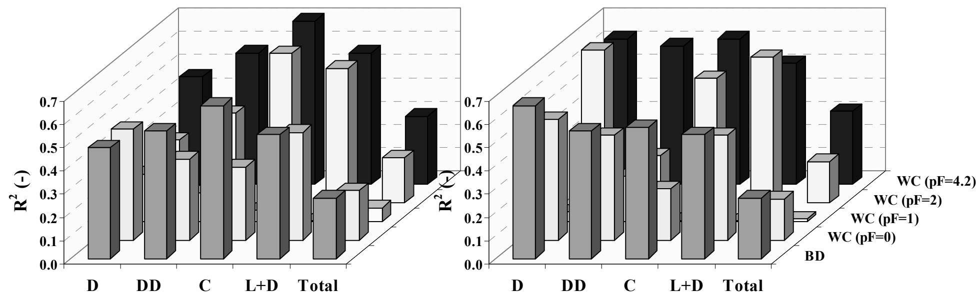

Figure 1. Determination coefficients (R^2) between the measured electrical conductivity values CF_EC (mS m^{-1}) (left) and P_EC (mS m^{-1}) (right) and soil properties measured in different tillage treatments. R^2 values are statistically significant (p>0.05) if $R^2 \geq 0.28$ (where n=12 per treatment) and if $R^2 \geq 0.05$ (where n=72 in total).

Figure 1 illustrates the determination coefficients (R^2) calculated between the indirectly measured bulk soil electrical conductivity (EC, mS m^{-1}) values and soil hydraulic properties ((bulk density (BD, kg m^{-3}) and soil water contents (WC, m^{-3} m^{-3}), corresponding to pF values of 0, 1, 2 and 4.2)). Moderately strong and statistically significant relationship between the instrument readings, BD, water content at field capacity (WC(pF=2)) and wilting point (WC(pF=4.2)) was found for the D, C and L+D treatments. Insignificant relationship between the studied properties and the EC values for the P treatment was found, most probably because of strong disturbance of soil surface layer and formation of clods.

The soil quality indicator S showed good correlation with the instrument readings in the disking treatment only (R^2=0.82 for multiple correlation with P_EC, FC_EC and PERR). The determination coefficients for the WC_infl and alpha were 0.74 (D), 0.64 (L+D) and 0.86 (D), 0.81 (L+D), respectively. For the other treatments, no significant relationships were found.

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Conclusions

Our results indicate that mechanical disturbance of soil and the corresponding structural changes influence the relationship between the field-measured soil electrical conductivity (EC) values and soil hydraulic properties. This assumes that this kind of measurements - performed on wet soils of a homogenous area - can be used to distinguish different kinds of soil tillage treatments in order to evaluate their sustainability. The EC values showed statistically significant relationship with soil hydraulic properties and quality indicators for treatments with more compacted topsoil layer. We concluded that further studies on the relationship between EC values and soil structural status should be carried out.

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