DETERMINING SOIL COMPACTION AT TRAFFIC LINES WITH PROXIMAL SOIL SENSING

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Abstract
Soil compaction introduced by large machineries is one of the major problems in crop production. There is need to assess the soil compaction in quick and reliable way. Soil proximal sensing technologies are robust tools for soil parameters determination. The aim was to assess two selected proximal sensing systems to determine soil compaction. As experimental site a CTF field was used, namely: crop bed (no traffic at all) and a traffic line (lines used for all traffic since 2009) areas. To characterize the differences in soil compaction, a vertical penetrometer was used which showed highly significant differences down to the depth of 70 cm. A horizontal penetrometer developed at Slovak university of Agriculture (measuring at 0.10, 0.15 and 0.20 cm depth) and soil conductivity sensor (EM38 – Geonics Limited) (measuring at depth range of 0.35 and 0.75m) sensors were used, both able to detect the differences at statistically significant difference of 0.01.

Key words: *CTF; electric conductivity; horizontal penetrometer.*

INTRODUCTION

Soil compaction is a major problem facing modern agriculture (*Hamza & Anderson, 2005*). It significantly affects the behaviour and the rate of physical - chemical and biological processes due to low porosity, low water and air permeability and increased requirements for traction power in seedbed preparation (*Badalíková, 2010; Chamen, 2011*). There are many factors which influence soil compaction. Besides the properties of soil itself (soil type, water and soil organic matter contents, etc.), the major factor is artificial. Other than incorrect management practices, the majority of soil compaction is caused by field machinery and its axle loads, wheel and tyre parameters, number of passes and drive slip. For example, the predicted pressure at 0.5 m depth in soils has increased by a factor of around six due to increasing loads over the past 80 years (*Chamen, 2011*). *Kroulík et al. (2009), Galambošová & Rataj (2011)* showed that 85% and more of the field area is trafficked during the season. Damaged soil structure after field traffic may be partly repaired by deep soil cultivation however the high cost of these operations may be reduced by site- specific tillage (*Chamen et al, 2015*). Other group of action is based on reducing/ avoiding soil compaction. To minimize the trafficked area, controlled traffic farming can be deployed, where the traffic is confined to the least possible area. The basic principle is establishing permanent traffic lines, which are used for all field operations and crop growth is mostly confined to the non-trafficked areas – crop beds (*Chamen, 2011; Chamen, 2003*). This system can be used for all field crops (*Peets et al., 2017*). Also, in these systems, the extent of soil compaction needs to be determined and a proper soil management needs to be design as the permanent traffic lines are drilled in most of the European CTF systems *(Galambošová et. al, 2017; Macák et al. 2018, Smith at al., 2014; Godwin et al, 2015*). Determining soil compaction is possible with tradition methods as sampling of undisturbed soil samples or vertical penetrometer measurements which are, however, time and cost consuming (*Rataj et al., 2014*). Therefore, rapid methods which enable to measure soil properties and produce soil maps with high resolution. Proximal sensing methods are well described in *Gebbers (2019),* he summarizes that as direct methods the penetrometers and draft force sensors can be used. As indirect methods, the electromagnetic induction, galvanic couple electric resistivity or ground penetrating radar methods can be used. There are published results on determining soil compaction by these methods (*Krajčo, 2007; Alaoui & Diserens, 2018; Romero-Ruiz et al. 2019*). However, there is still lack of evidence in terms of direct assessing the extend of soil compaction by these methods. This paper presents results of a pilot experiment comparing the two soil proximal methods used to determine the soil compaction at traffic lines namely soil conductivity and a horizontal penetrometer at a CTF experimental site.

MATERIALS AND METHODS

This paper presents a pilot assessment of two different soil proximal sensing methods used for soil compaction detection at traffic lines.

Experimental site

Soil sensors were used to determine soil compaction at an experimental site, where a long-term field scale experiment on Controlled traffic farming was established in growing season 2009/2010. The 16ha experimental field is located at University farm in Kolinany with silty loam in the top soil (0-350 mm) (51% silt, 30% sand, 19% clay). The different intensity of soil compaction is introduced through the controlled traffic of machinery at the field. The layout of the experiment and all the details are described in *Macák, et al. (2018)* and *Galambošová et al. (2017)*.

Data from soil proximal sensors were collected at two areas with different soil compaction conditions (Figure 2):

- Crop bed – non compacted soil (no field traffic since 2009/2010),
- Traffic line – permanent traffic line of the CTF system, all field traffic at this line since 2009/2010

To characterize the level of compaction at the areas, vertical penetrometer resistance was measured with a vertical penetrometer (Eijlkelkamp Soil & Water, Netherlands) and soil samples for soil moisture determining were taken at the same time. These data were used as etalon for the soil proximal sensing measurements.

Used methods of proximal sensing

Draft force sensor

A draft force sensor developed at Department of Transport and Handling was used (Figure 1). Details of the device are provided in *Varga, et al. (2014)*. The device measures continuously with two blades (one in non-compacted soil and one in compacted soil) and was originally designed to calculate the difference between the two blades which then is used to determine the relative extent of soil compaction. However, this sensor can be used also in conditions such as CTF field, where the traffic during measurement is confined to the traffic lines and different soil compaction conditions can be measured at the same time. The measuring device was aggregated with John Deere 8100 and the forward speed of 1 $km.h^{-1}$ was used. Measurements were taken along a selected permanent tramline as shown in Figure 2 in three depth horizons (10cm, 15cm and 20 cm).

Fig, 1 Horizontal penetrometer using h the two-argument comparative method - photograph from the measurement

Electromagnetic conductivity

The ECa (electromagnetic induction) was measured by EM38 MK2 (Geonics Limited, Canada) which provides measurements in the range to 0.35m and 0.75 m when in the horizontal dipole orientation. Measurements were conducted at the same positions as the soil force sensor described above. To ensure this, the RTK accuracy GNSS receiver (Topcon) was used for guidance during the measurement.

The DC-resistivity method is a method that measures spatially distributed voltages resulting from current injections throughout an array of electrodes typically arranged on the soil surface or in boreholes

Data analyses

Data were analysed with standard methods; one factor ANOVA with the LSD test were used to evaluate the differences of crop bed and permanent traffic line data. Software Statistica was used.

RESULTS AND DISCUSSION

Soil force sensor was used in 2018 and electrical conductivity sensor was used in 2019 season. Figure 2 shows the penetrometric resistance at the areas in those two seasons. *Siqueira et al. (2014)* reported overview of published results that that root growth can be restricted or even impeded when PR values vary between 1.0 and 3.5MPa or 2.0 and 4.0MPa. In 2018 were these limit values recorded for both areas, the crop bed reached the value of 2 MPa at the depth of 12cm and the permanent traffic line at 5cm. In 2019 were the values up to the limit value to the depth of 30 cm for traffic line and 60 cm for the crop bed, respectively. However, differences between the two areas of soil compaction (crop bed and permanent traffic line) were statistically significant in the whole soil profile as it was expected.

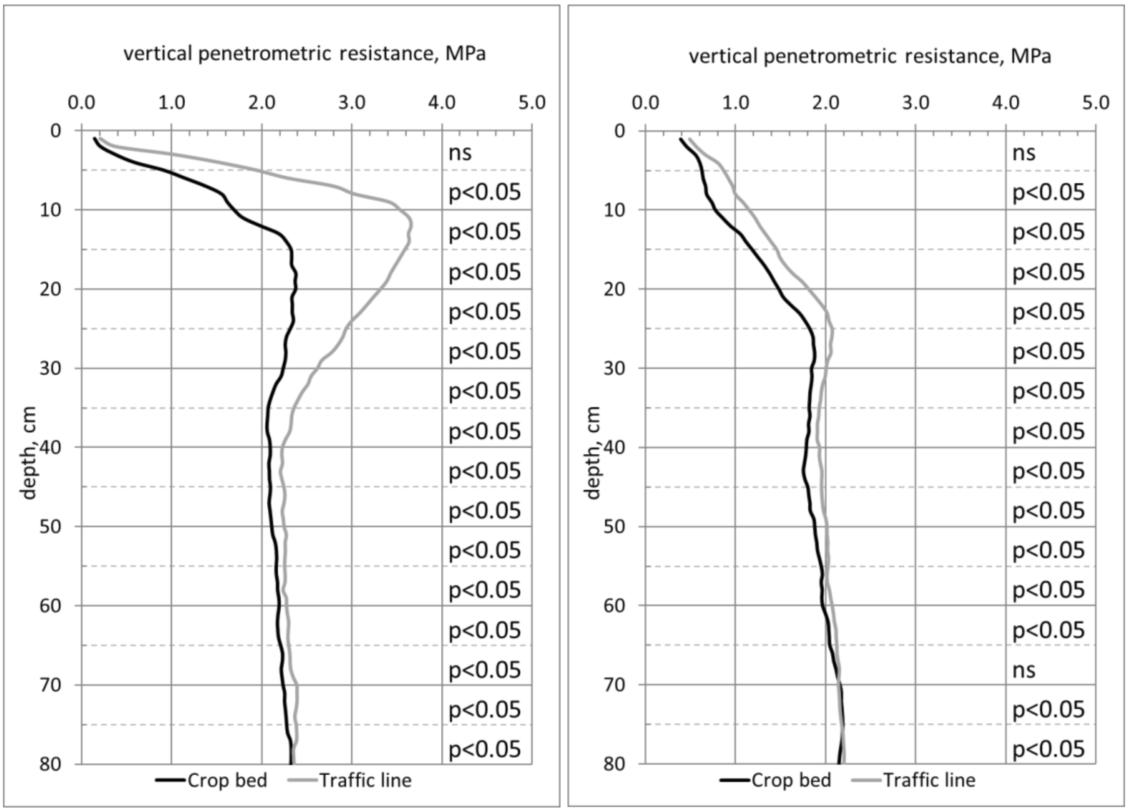

Fig. 2. Intensity of soil compaction in experimental zones represented by vertical penetration resistance (crop bed and trafficked lane) Left in 2018, right in 2019. Note: average of gravimetric soil moisture content in depth horizons 0-20 cm, 20-40cm and 40-80cm were 20.6%, 22.7%, 23.7% in 2018 and 23.4%, 22.5%, 22.6% in 2019, respectively.

Horizontal penetrometer

A horizontal penetrometer measuring the draft force was used in conditions of a soil moisture content of 19%. Results are given in Table 1 and Figure 3. Statistical analyses showed a significant difference in the median values for all depths and both soil moisture conditions at a level of p<0.010. The difference between the crop bed and traffic line decreases with increasing depth. This corresponds with the vertical penetrometer values, where also the difference decreases with increasing depth in the range between 10 to 20 cm. This shows the ability of the measuring device to detect the soil compaction differences across a small distance, which has potential use in assessing the conditions of permanent traffic lines in a CTF system, or e.g. measuring the effect of irrigation machinery on soil compaction (*Jobbagy et al., 2016*). Also, if used for field scale variability mapping, soil moisture and a GNSS location should be recorded as proposed by authors (*Naderi-Boldaji et al., 2016*) the areas for local tillage could be targeted (*Adamchuck et al., 2004*).

Tab. 1 Mean values, standard deviation and median values for data obtained by draft force sensor, (n>2500),
** p<0.01

Depth of measurement, cm	Compaction	Draft for, N average	± sd	Difference, N / significance
10 cm	Crop bed	1018.0	± 296.3	1260.7 **
	Traffic line	2278.7	± 427.9	
15 cm	Crop bed	1652.3	± 324.8	1186 **
	Traffic line	2838.3	± 374.4	
20 cm	Crop bed	3166.0	± 473.3	837.3 **
	Traffic line	4003.3	± 599.5	

<u>The soil conductivity sensor</u>

Results of soil conductivity measurements are provided in Figure 5. Here, measured values for the different soil compaction conditions (crop bed and traffic line) are presented for both depth ranges (C1 – up to 0.35m and up to 0.75 m).

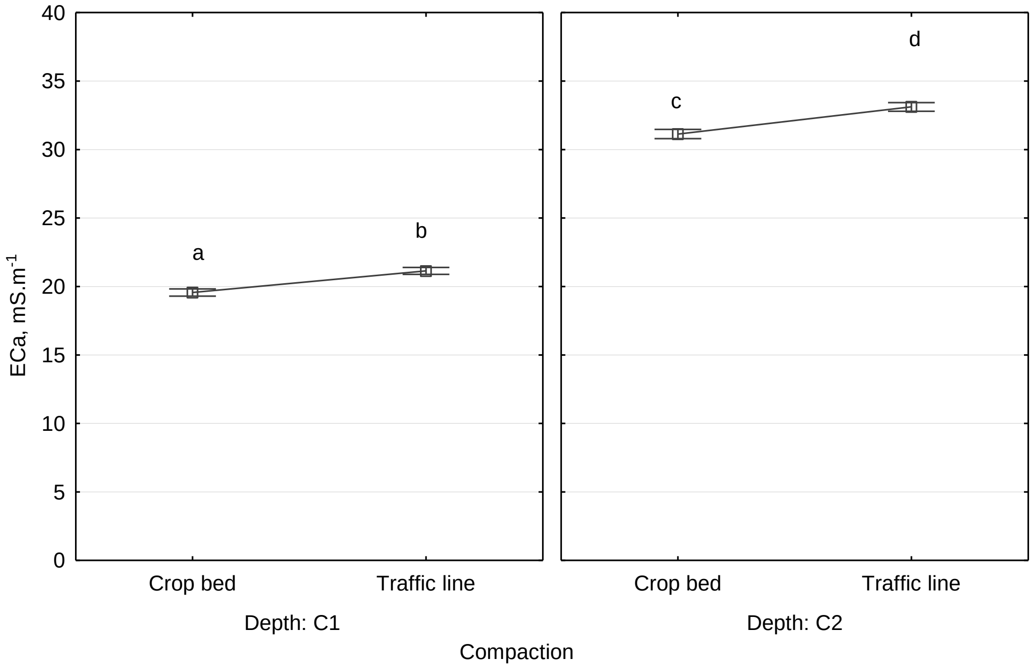

Fig. 5 Mean values of soil conductivity measured in crop bed and traffic line in 0.35m (C1) and 0.75 m (C2) depth, a,b,c,d - different letters denotes to different groups at p<0.01

Values of measured ECa are typical for this type of soil texture (*Domsch & Giebel, 2004*). For both depths, soil compaction increased the ECa values significantly.
The difference between measurement in crop bed and at traffic line were significantly different for both depths ($p < 0.01$). Up to date, there is lack of published knowledge on determining the soil compaction by electric sensors. In 2007, Krajčo compared different sensors and reported that the electromagnetic sensor distinguished the areas with no compaction above 0.3 m and areas with no compaction in whole profile with less precision.

CONCLUSIONS

Paper deals with selected soil proximal methods to determine soil compaction of permanent traffic lines at a CTF field, where permanent separation of crop bed and field traffic line has been used for 10 years. Data from a pilot study showed, that electric conductivity measured by the electromagnetic induction methods is a useful tool to distinguish between the compacted lines and crop bed for the depth ranges up to 0.3 and 0.75 m at a statistically significant level. This was alongside the tramlines. Future research should be done to exam the spatial resolution in the traffic lines should be determined. The horizontal penetrometer showed high sensibility in terms of determining the soil compaction in the upper layer. Here the local maximum of compaction was targeted by the sensor. Future work will be aimed on combining the sensor with soil moisture measurements and GNSS data and possible extension of the sensor in order to be able to measure different depths simultaneously.

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