MAPPING AND DIFFERENCES OF SOIL PHYSICAL PROPERTIES

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Abstract
Soil physical properties are of great importance for the evaluation of soil compaction or for soil conditions characterization. The latter option is important for the purpose of soil tillage machines. Field measurements were arranged in order to characterize the variation of soil physical properties within the plot. Two methods of soil physical characteristics evaluation were used: soil cone index and undisturbed soil sampling. Undisturbed soil samples were taken from 102 points in almost regular grid 6 x 6 m. Cone index was measured thrice in the each point. The maps of mentioned measurements were created and compared by using statistical methods. Penetration resistance generally copied soil bulk density but otherwise than expected. Nevertheless, the most important finding was that relatively very small changes of soil moisture content can influence penetration resistance regardless, or with minimal impact, of soil bulk density results.

Key words: soil bulk density, cone index, moisture content, soil properties.

INTRODUCTION

Soil compaction is a major problem of modern agriculture management and grows with size and weight of agricultural machines. For monitoring of soil compaction e.g. soil physical properties is useful to monitor bulk density and cone index values. These values are interrelated and influence each other. The main indicator of soil compaction is value of bulk density; it is a parameter that is often used to describe the level of soil compaction (JOHNSON & BAILEY, 2002). Relationship between soil compaction and physical properties of the soil at various depths were monitored by DEFOSSEZ & RICHARD (2002). In their work was created a model of the relationship between the density and depth of soil. Model of soil compaction was developed and then compared with measurements under real conditions. The main result was that the rides of agricultural technology are reflected in the depth of 0.35 m. Compacted soil has a higher density than non-compacted soil about 0.2 $t \cdot m^{-3}$ to a depth of 0.2 m. The influence of soil compaction has decreased to a depth of 0.45 m, where has achieved similar values as non-compressed soil.

Another very good method for monitoring physical properties of soil is a cone index measurement. Cone index measurement has advantages over measurements of soil bulk density in a simple acquisition of data from all over the soil horizon (this value is limited by penetrometer depth range), the process of penetration measurement can also be automated (RAPER, 2005). Values of cone index can be largely influenced by soil tillage as point's measurement of ALAKUKKU (1996). In the case of this measurement was performed plowing to a depth of 0.25 m. The increasing trend of cone index with depth indicates that there was no significant statistical difference between compacted and non-compacted areas to a depth where the plowing was conducted. Significant differences occurred only at depths where plowing was not performed (higher values for the compacted and lower values for non-compacted areas). The largest differences were observed at depths of 0.3–0.5 m, these differences were amounted to 22%. Nevertheless, the cone index values are to some extent influenced by soil bulk density but also by soil moisture content. AYERS & PERUMPRAL (1982) created a graph of the cone index, dry density and moisture content and their relationship for a soil with a share of 50% clay and 50% sand. Fig. 1 shows the significant influence of moisture content on cone index, while at higher moisture content the cone index is affected by the dry density only slightly. Similar measurement to the mentioned model was performed by VAZ ET.AL. (2011) who estimated correction which significantly lower the influence of soil water content on cone index measurements. Nevertheless, from their work is also obvious high influence of water content on cone index values.

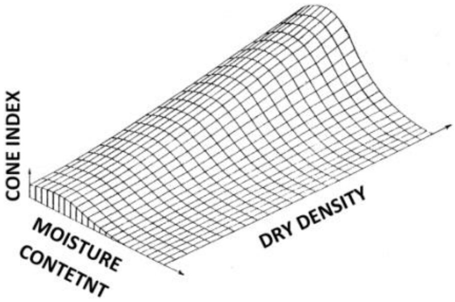

Fig. 1. – The relationship between cone index, dry density and moisture content (AYERS & PERUMPRAL, 1982)

This was confirmed by the experiment in which the penetrometer was combined with a TDR probe. The experiment was carried out on four parcels 1.2 x 1.2 m^2, wherein one plot was a reference and on the others was applied the water of the volume 100, 150 and 300 l. Results pointed to the fact that the increase in soil moisture by 0.05 cm^3·cm^{-3} can lead to reduction of penetration resistance up to 40% (VAZ ET AL., 2001). BUSSCHER ET AL. (1997) stated that the cone index values can be interpreted for known values of moisture content or with a suitable correction of cone index values using the equation related to the soil initial moisture content. However, using multiple-equation correction cannot guarantee that the resulting values and the differences are not just a result of these corrections. The result of this research was that the correction of cone index, for known water content, led to increased significance of differences. In the case of one-equation correction the difference had been influenced by differences in water content before correction. In the case of multiple-correction equation the difference may be real or a result of different corrections. Influence of soil moisture content on soil mechanical resistance was also mentioned in other works (VARGA ET AL., 2014; DA SILVA & KAY, 1997).

From literature it is obvious that great care must be taken when measuring the cone index with regard to, not only, bulk density but especially also to the soil moisture content. For that reason, this article focuses on interdependencies of soil moisture content, bulk density and cone index values within one plot and time horizon to provide authoritative results.

MATERIALS AND METHODS

Field measurements took place in the field near to Městec Králové in Central Bohemia, N 50°10.88725', E 15°17.78900'. The measurements were taken in 30th of October 2014. The soil type was classified as clayey-sandy *rendzina* according to FAO (Food and Agriculture Organization of the United Nations, 1974) and taxonomic soil classification system (TKSP in Czech Republic). Sugar beet was grown on the field before measurements.

Field test area was 46 x 100 m and two methods of soil physical characteristics evaluation were used: soil cone index measurement by horizontal penetrometer and undisturbed soil samples measurement. Undisturbed samples were taken into Kopecky's rings (stainless steel cylinders Fig. 2) and have standardized dimensions: 4.9 cm of diameter, 5.3 cm of height and volume of 100 cm^3. Undisturbed soil samples were taken from 102 points in almost regular grid 6 x 6 m from the depth of 0.1-0.15 m. Subsequently the data were evaluated according to VALLA ET AL. (2011). The content of the samples was weighed (weight of natural moist soil was obtained G_A (g)) and then put into the oven, which was set to a temperature 105°C, and the samples were dried for minimum period of 24 hours. After 24 hours drying the samples were re-weighted and weight of dry soil was obtained G_H (g). From the results it is possible to calculate the actual moisture content θ_m (%) of the soil,

$$\Theta_m = G_A - G_H \tag{1}$$

And soil bulk density ρ_d (g.cm^{-3}) was evaluated according to volume of sampling cylinders V (cm^3).

$$\rho_d = \frac{G_H}{V} \tag{2}$$

Fig. 2. – Kopecky's stainless steel ring during evaluation

Cone index was measured thrice in the each place of soil samples taking. In total, 306 cone index measurements were done. Cone index measurement was carried out to a minimum depth of 0.32 m and measurement results were saved for every 0.04 m of the depth. For the cone index measurement was used penetrometer Pn-10 with 30° cone angle and area of 1 cm^2. For future details see ASABE standard S313.3 (ASAE STANDARDS, 2004).
The number of points allowed to compare the results and to create maps resulted from both types of measurement.
Based on preliminary results from MS Excel and ArcGIS maps the data were divided into two groups with regards to soil bulk density map (according to Fig. 3).
In the first group were included the first 51 measurement points, where the values were found higher in bulk density. The remaining 51 points were included in the second group. This kind of distribution on the basis of soil bulk density is the core for comparison of results and the influence of soil moisture content and soil bulk density on the cone index. Subsequently, these two groups were compared statistically, by STATISTICA 12 software (see below), with respect to a sufficient number of measurements.
For the evaluation of the results was used program for map creation ArcGIS 10.1. Basic evaluation has been done via MS Excel 2010 and for statistical evaluation was used program STATISTICA 12 (*U-test, Kolmogorov-Smirnov test, t-test*).

RESULTS AND DISCUSSION

The maps were created from the measured values of soil moisture content, soil bulk density and cone index (Fig. 2–4). From map of soil bulk density (see Fig. 3) is a clear division of the plot into two similar parts. According to literature (JOHNSON & BAILEY, 2002; DEFOSSEZ & RICHARD, 2002) is obvious that the division of field is caused by different soil physical properties within the field (soil compaction). For this reason, the data set was divided into two similar groups, which were then statistically compared.

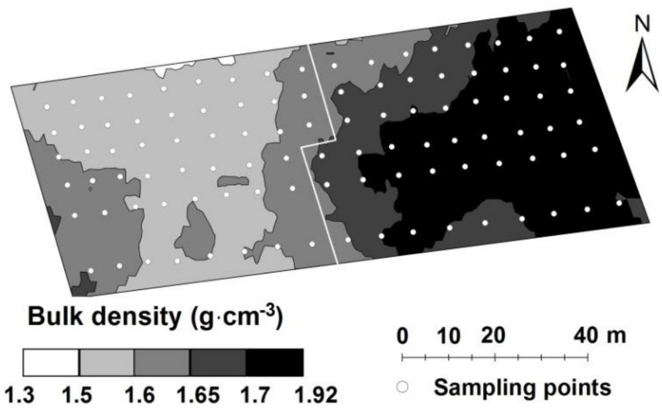

Fig. 3. – Map of soil bulk density (white line shows the division of land: left – lower bulk density 2st group, right – higher bulk density 1st group)

Upon closer observation of soil bulk density and cone index map (Fig. 4), was found an interesting finding namely at lower values of bulk density were the cone index values higher, whereas the opposite effect was expected. This finding contradicts the assertion (ALAKUKKU, 1996) that the cone index copies the soil bulk density as consequences of soil compaction. However, after taking into account soil moisture content values is all clear, because ALAKUKKU'S (1996) research was done under similar moisture content conditions.

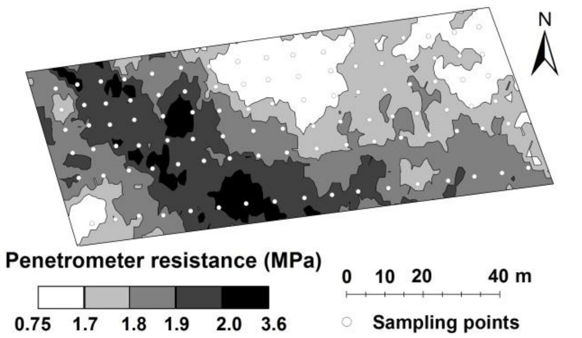

Fig. 4. – Map of cone index

By comparing maps of initial soil moisture (Fig. 5) content and cone index have been found areas where higher values of initial soil moisture content pointed out lower values of cone index and conversely. This finding was very surprising, since the soil moisture content affecting the cone index values more than soil bulk density in some areas. With regard to the hitherto mentioned results it is more than obvious that the cone index is to a certain degree affected by soil moisture content as was stated by AYERS & PERUMPRAL (1982), VAZ ET.AL. (2001; 2011) *etc*.

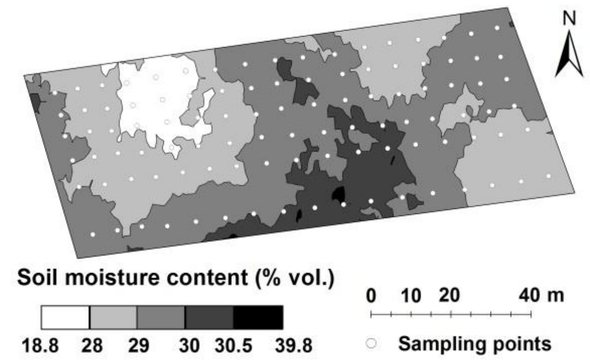

Fig. 5. – Map of soil moisture contetnt

Soil moisture content did not show a normal distribution, for this reason was primarily performed non-parametric test; however, a parametric test was also conducted. The result of initial moisture content is shown in Fig. 5. From the non-parametric test, it is clear that the groups differ in the distribution. The parametric test showed that the groups match each other in variability of soil moisture content, but there was a significant difference in average values. However, the parametric test is not inconclusive according the data distribution that's why the graph is not shown. From Fig. 6 is seen that group 1 has slightly higher average values in initial soil moisture content.

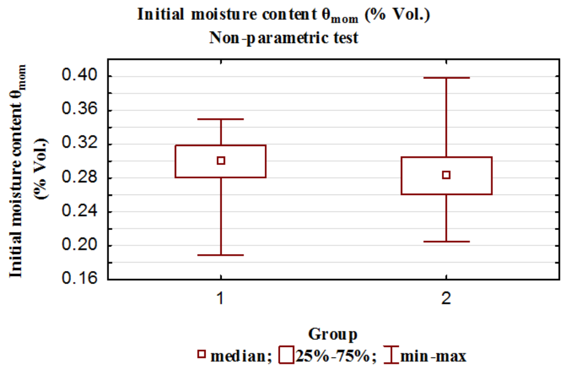

Fig. 6. – The values of initial moisture content by non-parametric

Soil bulk density values were classified as normal distribution, for this reason, has been used only a parametric test. The Fig. 7 indicates a statistically significant difference between groups of data measured for a soil bulk density. The figure also shows lower values of the second group. The difference between the average values is 0.13 $g \cdot cm^{-3}$ with very small confidence intervals. From a small confidence interval, we can assume a very homogeneous soil bulk density conditions in both groups. For this reason the soil bulk density was set as a core for comparison of measured values.

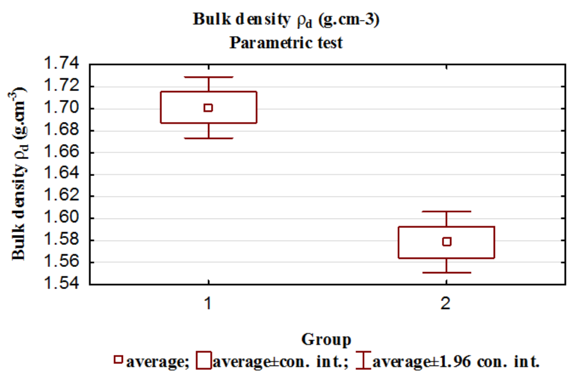

Fig. 7. – The results of bulk density

The cone index values, as in the case of soil moisture content, have not been determined as a normal distribution. As in the case of initial soil moisture content was performed as non-parametric as well as parametric test. Non-parametric test (Fig. 8) showed that there is no statistically significant difference, but the figure also points out slight increased values of the second group. If taking into account the parametric test, it is possible to detect statistically significant differences not only in average values but also in variability. Unfortunately as in the case of initial soil moisture content the parametric test cannot be taken in to account due to its inconclusiveness.

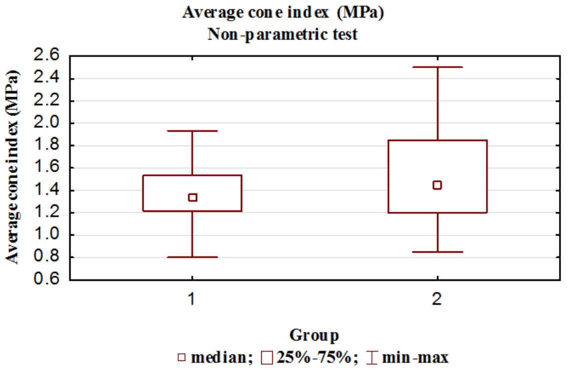

Fig. 8. – The cone index values by non-parametric (left) and parametric test (right)

From the measured values it is clear that the measurement area can be separated, on the basis of soil bulk density, into two groups, as was done. Based on the above figure of the soil bulk density could be assumed that the cone index values will be higher in the first group and lower in the second group. Results of cone index, however, showed statistically insignificant increase in the values in the second group (non-parametric test) and a statistically significant increase in the second group (parametric test - inconclusive). From the perspective of statistical evaluation could be said that the change of soil bulk density has no significant effect on the cone index value. But after taking into account the literature and soil moisture content we assume that the cone index copies the values of soil bulk and thus can indicate soil compaction for the same moisture content conditions within one field. Within this measurement and despite inconclusive statistical tests, we can assume that the cone index is largely influenced by the soil moisture content more likely than by soil bulk density, under these conditions.

On these foundations, we can assume a greater effect of initial moisture content on cone index, than effect of soil bulk density, under given conditions. Above results can also be affected by various factors such as a grain size composition of the soil, which, unfortunately, has not been included into this measurement.

CONCLUSIONS

Based on the results it was found surprising fact that at significantly lower soil bulk density were measured higher insignificant cone index values and conversely. This fact can be explained by soil moisture content. According to the literature can be said that the results of cone index are affected by soil moisture content despite the fact that there was not found statistically significant effect of soil moisture content on cone index measurement.

From the measured values is clear that the determination of soil compaction by cone index measurement without knowledge of soil moisture conditions can be very misleading. Therefore it can be only recommend to investigate soil moisture content for each measured point by penetrometer irrespective of the size of the field or take soil samples (soil bulk density values) and based on these values determine if the parts of field are or not compacted.

These results will be included in future evaluation of work of agricultural machinery, with regard to tensile ratios and the quality of work.

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