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Measurement of stubble cultivator draught force under different soil conditions

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Abstract. Knowledge of the energy demands of the machines for soil tillage is a useful factor for machinery design as well as farm management. It was decided to measure the draught force necessary for the operation of the stubble cultivator Ecoland 4000 from BEDNAR FMT Co.
The measuring set was composed as follows: pull tractor John Deere 8220 pulled by a rod in which the load cell was placed, another tractor John Deere 8345R. A cultivator type Ecoland 4000 (4 m working width) was mounted on the second pulled tractor. Measurements were carried out on two different soil types (light sandy and loamy) at operational speeds 6, 8 and 10 km h^{-1} and at two different adjusted depths of loosening.
The soil physical properties were characterized by cone index measurements which were measured with a penetrometer PN-10 with cone angle 30° and area 100 mm^2.
The results showed an about 30% increase in the draught force at work in clayey soil in comparison to sandy soil. Different quality of tillage was also observed on different soil types.

Key words: soil tillage, draught forces, soil properties.

INTRODUCTION

Soil mechanical resistance is an indicator of the mechanical properties of the soil. Soil mechanical resistance may be influenced by many factors such as: soil compaction, soil texture, water content, and other parameters (Adamchuk & Christenson, 2005). In trailed machines for soil tillage, the volume of draught force is critical with respect to the field operation energy demands. The draught force of soil tillage machines is affected by conditional parameters such as: tool type, working width, working depth, and working speed. The second area of factors influencing draught force are the factors dependent on the site, such as soil type, soil bulk density, soil moisture (Arvidsson et al., 2004), and relief (Schutte & Kutzbach, 2003). Other factors affecting the final value of draught force are tool condition and tool adjustment.

Paul (1992) performed mapping of draught force on the experimental plot of the Federal Agricultural Research Centre Institute in Braunschweig. A data logger recorded the signal from the strain gauge pins of the tractor and the speed measured by a radar. Besides the abovementioned, the author also recorded the overall slippage. The result of the measured values was in compliance with the dependence of draught force on various soil types within the experimental plot. Based on the results, Paul (1992) concluded that soil moisture significantly influenced the overall slippage of the tractor.

Van Bergeijk & Goense (1996) attached sensors on a modified mouldboard plough which sensed the working width and depth. Draught force was measured by strain gauge pins attached on the lower links of a three-pint hitch and by an additional measuring frame between the tractor and the mouldboard plough. The immediate position was recorded by a GPS receiver. The draught force when ploughing ranged between 30–50 kN m^2. Van Bergeijk & Goense (2001) repeated the measurement on the same field to determine the effect of the clay content in the soil on the draught force. After two years of experiments, the draught force values and maps prepared by the Kriging method showed high dependence of draught force on clay content.

Droll (1999) estimated the main sources of errors during measuring, such as: soil roughness, tractor and tool oscillations, speed differences, soil moisture content differences, variability of plot, etc. McLaughin et al. (2000) reached similar conclusions.

Kheiralla et al. (2004) used three steel octagonal ring transducers to measure draught on a three-point hitch. During the experiment on sandy clay loam soil, the following equipment was compared: mouldboard plough, disk plough, disk harrow, and rotary tiller. A similar experiment was performed by Chen et al. (2013). Chen performed an experiment with 180 mm wide sweep and with the angle of 80°. The experiments were performed at working speed 3.19 $km \cdot h^{-1}$ on three different soil types: coarse sand, loamy sand, and sandy loam. The results showed that the lowest values of draught force were observed with coarse sand soil (0.292 kN) compared to loamy sand soil (0.430 kN) and the highest values were observed with sandy loam soil (0.585 kN). These results were used for a discrete element model for soil-sweep interaction. Similar measurements were performed even before 1996 by Glancey et al. (1996).

Current knowledge of draught force could be a useful tool in many ways. The results can be used in routine practice to compare the energy performances of tillage technologies, for verification of technical changes to working tools, working tool optimization, and verification of agronomical measures (Kroulík, 2013).

MATERIALS AND METHODS

Field measurements took place in Písková Lhota in Central Bohemia. The measurements were taken on the 10th of October, 2013.The soil type was classified as mostly sandy and loam. Spring barley was grown on the field before the measurements with an average yield of 5.2 t ha^{-1}. Straw was crushed and dispersed on the land during harvest. After the harvest, the stubble was loosened by a mounted disk cultivator of Stromexport (BEDNAR FMT) ltd. to the depth of 0.1 m in August 2013. The fields were sprayed three weeks before measurement (liquidation of second growth) with a non-selective herbicide (glyphosfate).

The tractor John Deere 8220 and cultivator Stromexport (BEDNAR FMT) ltd. Ecoland EO 4000were used to measure the tensile draught force. The working width of the machine was 4 m. For actual measurement, an instrument for measuring draught force developed in collaboration of the Czech University of Life Sciences and BEDNAR FMT ltd. (formerly Stromexport) was used. John Deere 8345R (Fig. 1) served as the pulling tractor. The tractor John Deere 8220 had an engaged gear and was released during measurements and served only for lifting and lowering of the cultivator. The draught force was provided only by the tractor John Deere 8345R.

Figure 1. Measuring set. From right: pulling tractor John Deere 8345R, measuring instrument, pulled tractor John Deere 8220 for lifting and lowering of the cultivator, cultivator Ecoland EO 4000.

A basic part of the measurement apparatus was a strain gauge load cell S-38 with the measuring range of up to 200 kN. The load cell had to be placed into a steel cage so that forces were applied only in tension or compression. Bending of the load cell may cause its destruction. The load cell was calibrated on a stationary workplace. Callibration was carried out on a tensile testing machine ZDM 50t. The data from the load cell were sensed every 2s into a laptop which was situated in the cabin of the tractor. The measuring equipment was complemented by hinges for mounting between the pair of tractors (Fig. 2).

Figure 2. Measuring equipment between the pair of tractors.

Firstly, series of measurements were performed without recess of the cultivator. This measurement was used to determine the rolling resistance of the tractor with a tiller. Then the cultivator was set at processing depth 0.1 m. The measurements were performed with the tiller lowered at speeds of 6, 8 and 10 km h^{-1}. The measurements were performed on light sandy soil and consequently on loamy soil in the second part of the plot. Then, the working depth was set to the depth of 0.15 m. Again, the measurements were made for alternative speeds 6, 8 and 10 km·h^{-1}. The measurements were also performed for both types of soil.

Additional measurements of the physical properties of the soil were carried out by a penetrometer PN-10 which was developed at CULS Prague. It uses a probe with a cone angle of 30° and area of 100 mm^2. Furthermore, the transverse profile of the soil was uncovered for determination of the quality parameters of the tillage.

RESULTS AND DISCUSSION

The calibration results and calibration curve can be seen in Fig. 3. The linear dependence of the measuring apparatus output frequency on tensile force was proved. The resulting linear dependence was used as a calibration equation for draught force calculation.

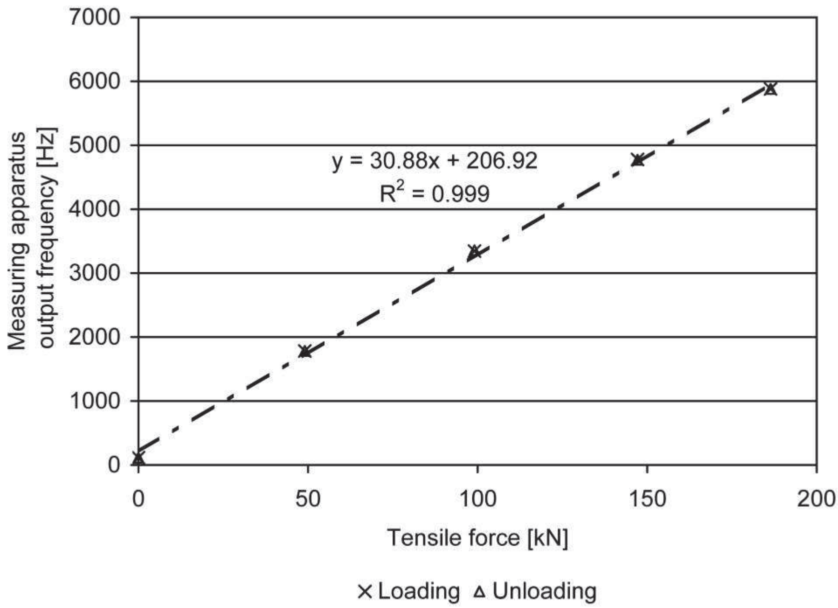

Figure 3. Dependence of the measuring apparatus output frequency on tensile force. Load cell calibration curve.

The graph in Fig. 4 shows the measured results of the loosened soil to the depth of 0.1 m, the measured values are relative to 1 m of width. The cultivator worked at the upper limit of its working range. The soil was intensively lifted and blended by the tines. Only the upper part of the soil profile and the crushing effect caused by the tines were cut off. These facts also correspond to the process of measuring. The results showed a linear increase in draught force along with the working speed. This applied for sandy soil and loamy soil. Furthermore, the results demonstrated the influence of soil type on draught force. Increased traction in soils with a high content of clay particles was observed at all operating speeds.

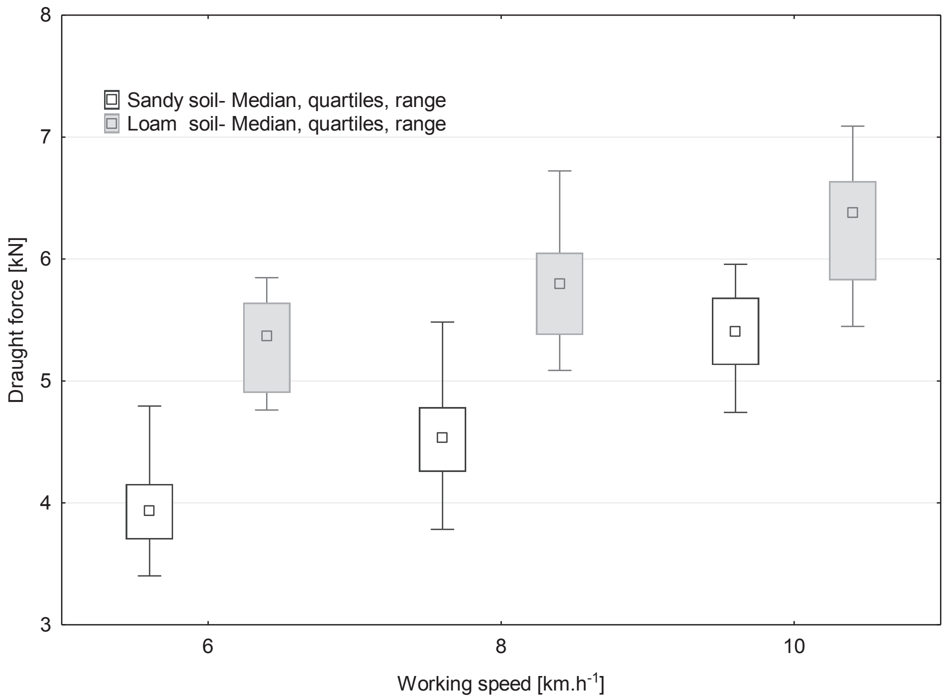

Figure 4. Dependence of draught force on working speed for sandy and loamy soil – working depth 0.1 m.

Fig. 5 shows the results of the measurement of tensile force at the depth of 0.15 m. The cultivator worked very intensively with the change of the working depth. The soil was picked up and intensively mixed with crop residues by the tines. The work of the cultivator showed improvement of qualitative parameters (soil mixing, breast size, cross profile of bottom). The course of tensile draught force was quite different from the measurements at the depth of 0.1 m. No correlation between the increased tensile force and working speed was found. Conversely, a greater dependency on the soil type can be observed. This is probably caused by movement of the soil over coulter and its surrounding areas. A soil layer was created in the course of work that was moved with the tines during the movement forward. The weight of this material probably increased draught force. At the same time, it may not decrease with decreasing working speed.

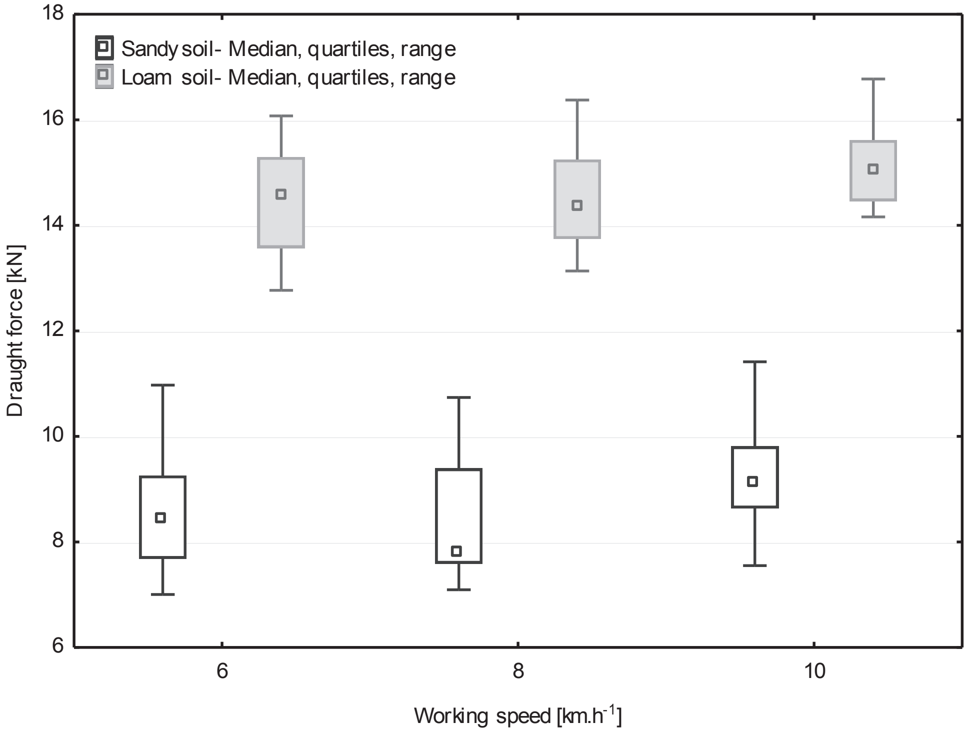

Figure 5. Dependence of draught force on working speed for sandy and loamy soil – working depth 0.15 m.

Measurement of the cone index is shown in Fig. 6. The cone index is graphically expressed for 4 depths. The figure shows that a higher content of clay particles in the soil influenced the cone index values. This is likely due to the different soil moisture content. For example, in the surface layer, the average moisture content of sandy soil is below 8.7%. The cone index value increased significantly with measured depth, which can be expected in these types of soils. The impact of soil tillage technology was also evident. In this case, reduced soil tillage had been conducted for several years. There was no obvious layer of soil, which would be significantly compacted (e.g. technogenic compaction). In contrast, relative to the absolute values of the cone index of soil, the soil was in good condition in terms of physical properties.

The research results confirmed the conclusions about draught force research in the area of soil tillage (Chen, 2013; Glancey, 1996; Paul, 1992; Arvidsson et al., 2004; Schutte & Kutzbach, 2003).

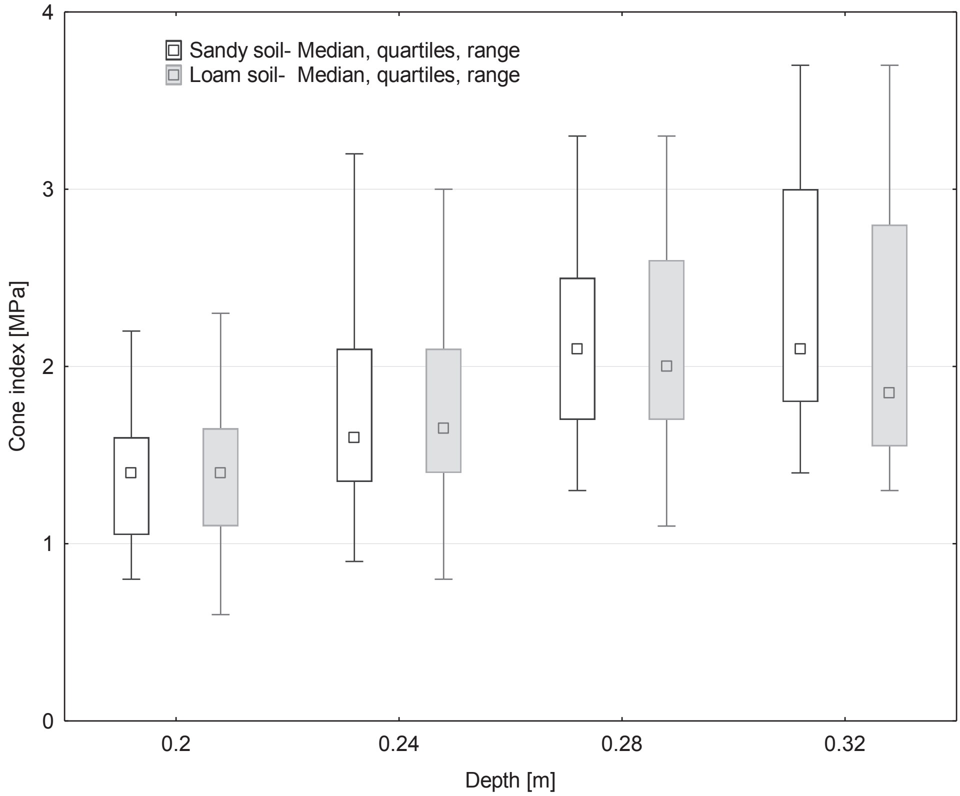

Figure 6. Results of the cone index measured by a penetrometer PN-10 on sandy and loam soil.

CONCLUSIONS

The measurements showed the influence of soil type on draught force during the measurement of ploughshare plow. Conversely, the influence of working speed on draught force has not been proven when using this cultivator. However, it can be assumed that a different type of cultivator tines with different geometries would behave in a different way in terms of tensile strength under these soil conditions, depending on the depth and forward speed. When selecting the cultivator, it is always advisable to perform a test operation in the conditions where the cultivator will be used. It is used to optimize the costs in terms of fuel consumption, wear of the tines, and time management in compliance with agro-technical terms.

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