Agronomy Research **13**(1), 186–191, 2015

Evaluation of measuring frame for soil tillage machines draught force measurement

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Abstract. The knowledge of energy demands of the machines for soil tillage is useful factor for machinery design and also farm management. Currently used methods of draught force measurement are based on the use of the measuring rod. Basic part of this measurement apparatus is strain gauge load cell which is protected against damage by steel cage so that the forces were applied only in tension or compression. The main disadvantage of this solution is the necessity of using two tractors for the measurement: pulling one and pulled one equipped with soil tillage machine.

To avoid this disadvantage, measuring frame for soil tillage machines draught force measurement was developed. For the evaluation of measuring frame function consequent measurement arrangement was used: crowled tractor John Deere 8320 RT as a pulling device, measuring frame mounted on its three point hitch, measuring rod connecting measuring frame and pulled wheel tractor New Holland T7050 and Köckerling Exact Gruber Vario soil tillage machine with 5 m working width.

When comparing draught force results from strain gauge load cell placed into measuring frame with those from measuring rod it was found that there existed no statistically significant difference between the data from measuring frame and measuring rod. Measuring frame can be used for the aim of soil tillage machines draught force measurement and pulled tractor is not necessary in this case.

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

INTRODUCTION

Root restricting soil layers reduce crop yield (Topakci et al., 2010). It's usual to use subsoiling method to remove barrier of compacted soil which mainly caused by agriculture transport across the field (Hall & Raper, 2005). One of indicators of mechanical properties of soil is a soil mechanical resistance (Adamchuk & Christenson, 2005). Soil mechanical resistance involves soil compaction, texture, moisture etc. One of measurable parameters of soil mechanical resistance is drought force measurement. The drought force is affected mainly by soil conditions (soil type, compaction, relief etc.) (Schutte & Kutzbach, 2003) and by parameters of tillage machines (type of working tool, working width, working depth etc.). 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 performance of the tillage technologies, verification of technical changes on working tool, working tool optimization and verification of agronomical measures (Kroulík, 2013).

Draught force measurement is a good tool for site mapping as evidenced from Paul (1992) measurements. During this measurement the data were logged from the strain gauge pins and from speed radar. Besides abovementioned the author recorded also overall slippage. Result of the measured values was in compliance of dependence of draught force on various soil types within experimental plot. Based on the results Paul (1992) concluded that soil moisture significantly influenced the overall slippage of the tractor.

Novák et al. (2014) performed the draught force measurement by load cell with measuring range up to 200 kN. This load cell was mounted between draw able and drawn tractor which was connected the measured cultivator. These measurements were carried out for three different speeds (6, 8, 10 km h^{-1}) and two working depths (0.1 and 0.15 m) at two different soil types (sandy and loam soils). The result of Novák et al. (2014) measurement was a confirmation of the influence of soil type on the draught force however the impact of speed on draught force was not proven.

Very important measurements were carried out by Droll (1999) who 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.

Another parameter which would indicate the mechanical strength of the soil is cone index measurement by penetrometer according to ASAE (2004). By penetrometer measurement can be estimated the depth of the compacted layer and then the subsoiler can be adjusted to the proper depth (Hall & Raper, 2005), than the subsoiler could break the compacted layer of soil. Penetrometers with vertical axis of cone penetration into the soil are standardly used nevertheless there are also available the penetrometers with horizontal axis of penetration called horizontal penetrometers. Horizontal penetrometers are good helpers for continuous mapping of the plots variability. There are a lot of types of horizontal penetrometers which do not always use the cone which penetrate the soil.

For example, Varga et al. (2014) used simple two blade horizontal penetrometer with load cell located on the three point hitch frame. Interesting measurement carried out by Hall & Raper (2005) where the sensing element was in shape of 30° wedge and also mentioned that penetrometer measurements are largely influenced by soil moisture.

The combine measurement of cone index by horizontal penetrometer and soil moisture content showed Lammers et al. (2007) and Naderi-Boldaji et al. (2012) both designed and constructed cone horizontal penetrometer where the cone already contained a capacitive sensor. These combined ‘on the go’ sensors confirmed significant influence of soil moisture content on the cone index measurement.

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. Sugar beet was grown on the field before measurements with an average yield of 85 t·ha^{-1} at 16% sugar content.

Tractor New Holland T7050 and cultivator Köckerling Gruber Vario was used to measure the draught force. The working width of the cultivator was 5 m. For actual measurement, two measuring instruments of draught force (stick and frame) developed in collaboration of BEDNAR FMT ltd. (formerly Stromexport) and Czech University of Life Sciences were used. As a pulling tractor means served crawler tractor John Deere 8320RT (Fig. 1). Tractor New Holland T7050 had engaged gear and was released during measurements and served only for lifting and lowering of the cultivator. The draught force was provided only by John Deere 8320RT tractor.

Figure 1. Measuring set. From left: pulling tractor John Deere 8320RT, measuring frame, measuring stick, pulled tractor New Holland T7050 for lifting and lowering of the cultivator, cultivator Köckerling Gruber Vario with 5 m working width.

Basic part of both measurement devices was strain gauge load cell S-38 with measuring range up to 200 kN. Detailed description of measuring stick can be found in Novák et al. (2014). Draught force measuring frame was newly developed instrument. Its design can be seen in Fig. 2. Measuring frame is connected to three point hitch (3) of pulling tractor. Strain gauge load cell (2) and horizontal penetrometer (4) are also integrated to the frame. Two point hitch (1) serves for the connection of soil tillage machine.

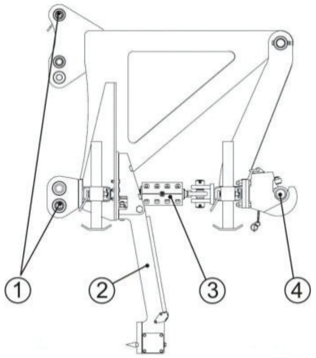

Figure 2. Draught force measuring frame: (1) connection to three point hitch of pulling tractor, (2) vertical penetrometer, (3) strain gauge load cell (200 kN), (4) two point hitch for soil tillage machine pulling.

The data from both load cells placed in measuring stick and frame were sensed with 6 Hz frequency by A/D converter NI USB-6008 and saved into notebook which was situated in tractor cab. This information was supplemented by machine location data from DGPS receiver Quectel L16 and signals form horizontal penetrometer.

Penetrometer used sensing element in shape of 30° conical wedge with 30 mm diameter and 56 mm length. Sensor Zemic B3G-C3-1.0t served as a force sensor on conical wedge sensing element. Measuring frame was also equipped with ultrasonic distance sensor UK1D-E1-0A for actual cultivator working depth measurement.

Prior field tests the area of 46 x 100 m was selected from the field and the measurements were done in order to characterise soil physical properties. Those measurements were carried out by horizontal penetrometer and by taking and evaluating samples of Kopecky's cylinders. Horizontal penetrometer PN-10 was developed at CULS Prague. It uses a probe with a cone angle of 30° and area of 100 mm^2. Penetrometer measurements were done at 204 places of above mentioned area up to 400 mm depth. Penetration resistance was estimated for each 50 mm depth during each measurement.

102 of Kopecky's cylinders samples were taken from the depth of 150 mm in order to as accurately as possible characterise soil bulk density, porosity and moisture content.

In order to evaluate the accuracy of draught force measurement by measuring frame in total three 100 m long measuring passes were performed with set cultivator working depth at 150 mm. Draught force signals from measuring stick and measuring frame together with vertical penetrometer resistance were observed in this case for next evaluation. Furthermore, the transverse profile of soil was uncovered for determination of quality parameters of tillage at the end of the measurements. Microsoft Excel and Statistica 12 computer programmes were used for statistical evaluation of the results obtained.

RESULTS AND DISCUSSION

Fig. 3 shows a typical example of values obtained with lowered cultivator during one measuring pass. The figure shows similar progress of measured values for both the measuring frame and stick. Both curves can be considered as real progress of draught force caused by cultivator resistance. Small difference in the courses of values can be explained by the sensor sensitivity and its calibration. Also measuring frame is equipped with joint mechanism as opposed to purely draught dynamometer system (measuring stick).

From the graph in Fig. 3 it is also evident the course of measurement by horizontal penetrometer. This can be seen as complementary measurements to the measurements of draught force. It is also necessary to mention the fact that the curve of the horizontal cone index has a time offset against curves of draught forces. This was caused by displacement of horizontal cone index against the cultivator. The course of values in the early stages is also influenced by setting of measuring frame at the working depth in relation to the cultivator recessing. From the course of cone index values can be assumed the partial copying of the draught forces during measurement. The increase of cone index values follows the rise of the draught force values. Although the values of cone index and draught force cannot be simply compared, its resistance is undoubtedly one of the parameters that appropriately describe the draught strength.

Fig. 4 shows values of draught force at steady state (in the range of 30 to 80 s) using both measuring devices. As seen, the measurement using the measuring frame has a lower range of measured values (due to smaller oscillations) than the measuring stick. This is probably due to different imposition of sensor that has a lower tendency to oscillate. Another fact is the partial difference in the measured values. These can be caused by a slightly different design of the sensor, which cannot eliminate the influence of its imposition in relation to the construction of the measuring device. This may cause some distortion of values due to the transferred forces in the imposition. Nevertheless these deviations cannot cause significant distortion of values due to the high measured values and the errors are constant for each measuring devices.

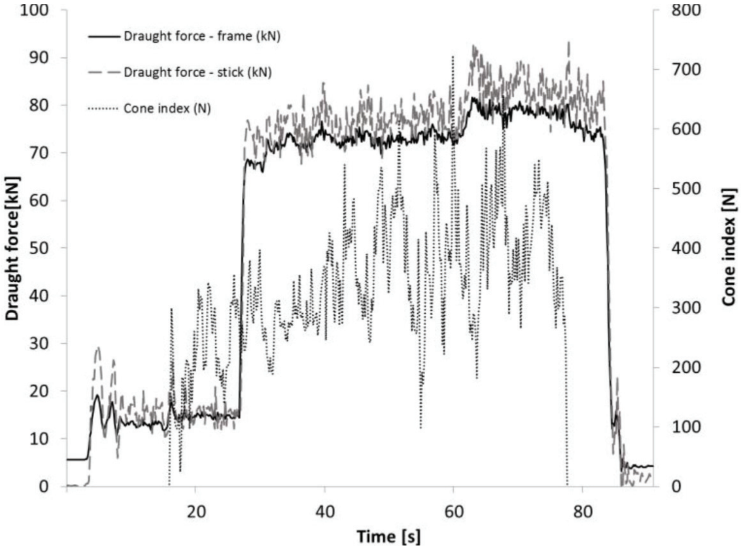

Figure 3. The course of measured values of draught force and cone index during one of three measuring passes.

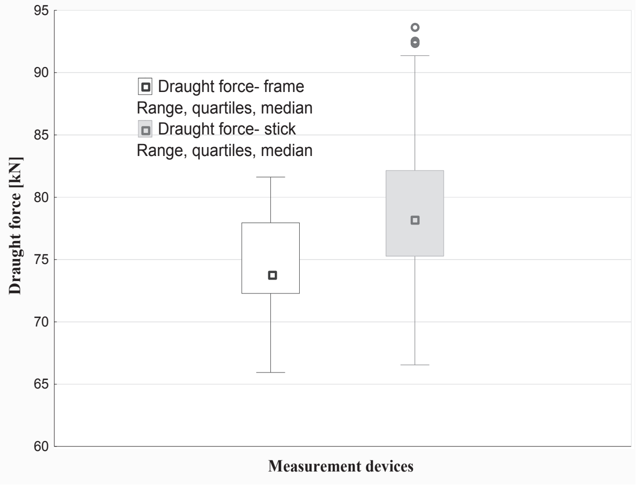

Figure 4. Draught force values between 30–80 seconds (constant measurement conditions).

Deep analysis of the influence of changing soil properties on horizontal penetrometer cone index and draught force measurements is unfortunately just out of the scope of this article. It will be discussed in some of forthcoming articles later.

CONCLUSIONS

Measurement of draught forces is an important area at objective evaluation of agricultural technology. Using specialized measuring devices is the most accurate method of measurement so far. The alternatives (e.g. using data from tractor information system) do not reach accuracy of this basic method. The advantage of using the specialized frame is the possibility to use only one tractor instead of two ones. Drawn tools may be directly connected to measuring frame by two point hitch because draught force measurement results are similar. Additionally, this method is not distorted by a change of rolling resistance due to the fact that there is no preceding passage of the tractive tractor. Supplementation of the measuring frame by the horizontal penetrometer further expands the possibilities of using the measured values for rapid characterization of the soil surface layer state.

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