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Measurement of tensile force at the fundamental tillage using tractor's build-in sensor and external sensor connected between machines and their comparison

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Abstract. The value of tensile force during soil tillage is crucial for estimating the energy performance of trailed machines.
For tensile force measurements, a mouldboard plough with working width of 4 m was used. The ploughing speed was approximately 7 km h^{-1}. Measurements were carried out on two plots with different soil texture. Loam-sandy soil dominated on the first plot, whereas clay soil dominated on the second one. The slopes of the plots are 1.1° and 2.4° respectively. Both plots have been left without stubble modification after harvest. The dynamometer LUKAS type S-38 was used for measuring tensile force. The dynamometer was placed on a hinge, which was positioned between two tractors. As a second method of tensile force measurement, electro-hydraulic hitch sensors were used, from which the values were recorded.
The obtained values of tensile force were approximately 30 kN on the first plot and 54.3 kN on the second plot. The interdependence values of tensile forces between internal and external sensors showed a high coefficient of determination $R^2 = 0.91$ in regression data analysis.
The comparison of tensile force measurements using a special dynamometer and electro-hydraulic tractor sensor proved that the outputs of serial sensors can be used for the continuous monitoring of tensile forces during operating the machine. The automated storage of data collected from tractor sensors during tillage can greatly simplify this work, while no additional expenses are incurred to obtain data. Thus, the findings can be used to determine the variability of the land.

Key words: force sensing, soil tillage, tensile force, soil variability, soil mapping.

INTRODUCTION

The high price of sampling and laboratory analysis supports the development of sensors that will evaluate the required soil properties, for example, during towing sensors across a field (Adamchuk et al., 2004; Viscarra Rossel et al., 2011). The deployment of these sensors will facilitate an overall reduction of data collection costs and the optimization of the sampling grid.

Soil mechanical strength is an indicator of the mechanical properties of soil. This strength can be affected by compaction, soil texture, water content and other agricultural parameters (Adamchuk & Christenson, 2005). A number of prototype systems were developed for mapping soil mechanical strength during machine operation. The higher sampling frequency of these techniques provides a much more accurate representation of the variability of soil mechanical strength inside the field, compared with the data obtained from point-sampling with a cone penetrometer.

Barone & Faugno (1996), Sirjacobs & Destain (2000), Mouazen et al. (2002) and Novák et al. (2014) discuss sensors for measuring soil compaction and monitoring physical properties in order to gain knowledge of locally different soil properties. In their experiments, they measured the force necessary for drawing the tool or biting in the soil at constant speed. Mouazen et al. (2005) evaluated tensile forces in motion with a unilateral blade that was equipped with strain gauges. In those cases, the tool could be also called a horizontal penetrometer. These systems meet the requirements of continuous recording to a much greater extent.

Sirjacobs et al. (2002) used tools like the plough coulter in their experiments. During the measurement, physical parameters that affect the size of tensile force were monitored. Verschoore et al. (2003) compared the horizontal penetrometer with a measuring chevron chisel in order to investigate the forces acting on the working side of the chisel. On the basis of small differences in correlation coefficients, the authors see a great future for measurements in this field ,but emphasize that their findings must be confirmed with further measurements.

Van Bergeijk & Goense (2001) found that there is a relationship between tensile strength and different soil types on an experimental plot. The authors state in conclusion that it is possible to use a tractor's serial tension pins for measuring tensile force, if the proper calibration is performed prior to measurement.

As further stated by Kürsteiner (2003), force measurement at 3-pt. hitch is often performed using measuring frames that are inserted between the tractor and the implement. Working with and handling such frames can be very difficult. In addition to the results obtained with experimental frames, the standard force pins of the tractor, designed for electronic linkage control, can be also used for measurements (Schutte & Kutzbach, 2003).

The measurement of differences in soil properties during normal tillage is the basic tool for tensile force mapping. Moreover, as noted in the work of Rothmund et al. (2003), tensile force can be measured through an electronically controlled 3-pt. hitch, and automated data storage is available at no additional cost during tillage. Kutzbach et al. (2004) dealt with verifying experimentally detected values with values obtained from the tractor during field operations. The authors conclude that the findings can be used to determine the variability of the field.

MATERIALS AND METHODS

A four-share reversible plough with the working width of 4 m was used for measuring tensile forces in field conditions. The operating speed of the plough was set to 7 km h^{-1}, which corresponds to the working speed recommended by the manufacturer. The seven-blade plough Kverneland was attached to the tractor John Deere 8320. Measurements were carried out on two plots which differed in particle size distribution composition of the soil. The experimental agricultural field is located in the central part of the Czech Republic. It represents intensively exploited arable land with commonly planted crops such as canola, spring barley, winter wheat and corn. The area is in a typical temperate zone climate with the average annual temperature ranging from 7 to 8.5 °C and with 500 to 750 mm of annual precipitation. Plot No. 1 contained mainly loam-sandy soil. The average slope of the plot was 1.1°. The landscape is gently rolling with an altitude ranging from 476 to 470 m. The main soil unit is *Eutric Cambisol* (classification system World Reference Base). Plot No. 2 contained mainly loamy to clayey soils. It also had a higher average slope of 2.4°.The landscape is gently rolling with an altitude ranging from 440 to 460 m. The main soil unit is *Dystric Cambisol* (classification system World Reference Base). Both plots were left without stubble modification after the harvest. The soil moisture ranged from 26.4 to 28.6 vol% during tillage.

For tensile force measurement, the tensile dynamometer LUKAS type S-38 with a measuring range of 200 kN was used. The dynamometer was placed in a hinge, which was positioned between two tractors (see Fig. 1). The dynamometer's outputs served as a reference value for measuring tensile force using an electro-hydraulic hinge sensor for a tractor. Data were simultaneously stored in a data logger. Position values of the machine collected from a GPS receiver were also recorded with the individual records.

Figure 1. The measuring set during the measurement of tensile force using the tensile dynamometer LUKAS type S-38.

The experiment started with the measurement of a two tractor set without ploughing to ensure the measurement of the rolling resistance of the whole drawn working set (tractor and plough).

As a second way of tensile force measurement, values from a three-point hitch electro-hydraulic sensor were used. Tensile force values were recorded with a 2 s interval. Tensile force was mapped using an electro-hydraulic hitch control for tractors (3-pt. hitch) only on plot No. 2.

RESULTS AND DISCUSSION

The dependence of the tensile force of a 3-pt. hitch on the values received from the dynamometer LUKAS type S-38 is shown in Fig. 2. This dependence of tensile forces is supported by Fig. 3, which reveals that the tensile force values from both sensors were very similar.

Fig. 2 describes the dependence of tensile force values regarding the 3-pt. hitch on the tensile force values measured with the dynamometer. The comparison and evaluation of these two data sets were performed by means of regression and correlation analysis. The figure also shows the results of the discussed analysis. The determination coefficient value ($R^2 = 0.73$ and 0.91) is listed in the legend of the figure. The calculated value p was far lower than the chosen significance level $\alpha = 0.05$ in our case, thus, it may be claimed that the correlation coefficient is statistically significant. Generally, the whole regression model is classified as statistically significant. The regression formula is shown in Fig. 2 as well.

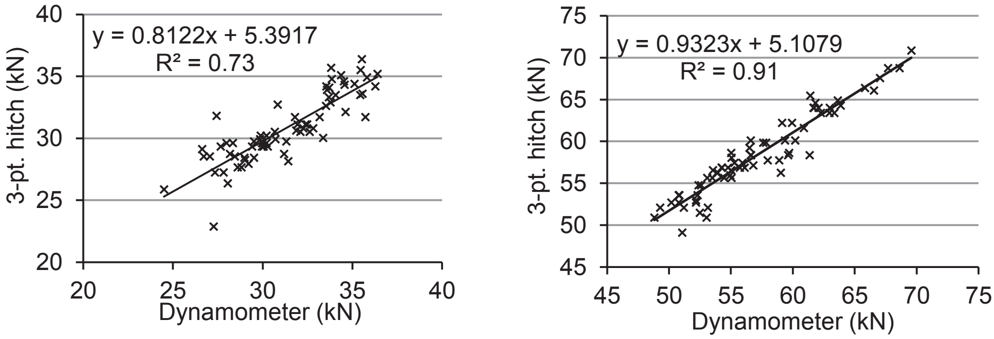

Figure 2. The dependence of the tensile force of a 3-pt. hitch on the values received from the dynamometer LUKAS type S-38 measured on field No. 1 (left side) and field No. 2 (right side).

The tensile force time records collected from both sensors are given in Fig. 3 and 4. This confirms the results of the correlation and regression analysis; it is possible to observe the progress of the values on the timeline.

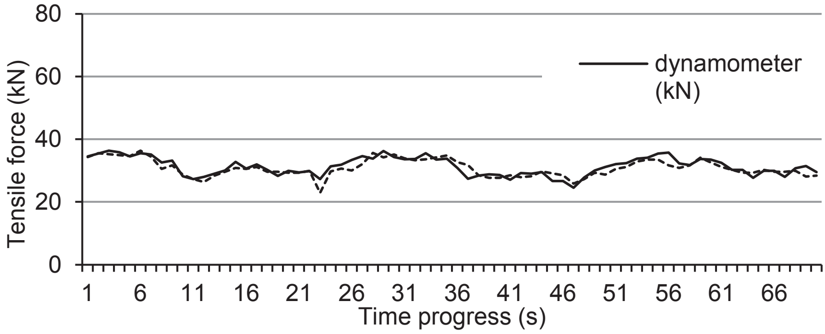

Figure 3. Time record of tensile forces measured with a tractor's in-built sensor and the dynamometer LUKAS type S-38 on plot No. 1.

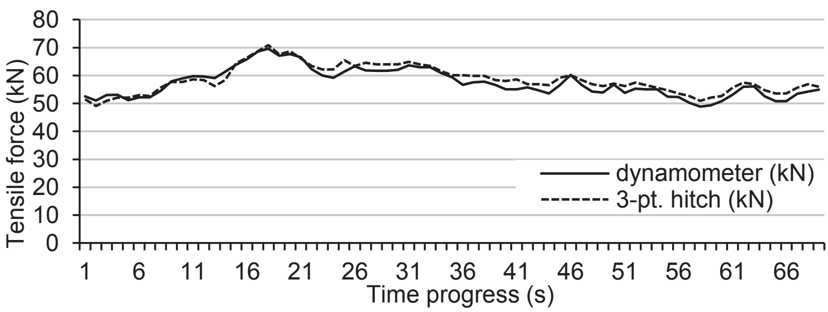

Figure 4. Time record of tensile forces measured with a tractor's in-built sensor and the dynamometer LUKAS type S-38 on field No. 2.

The trendline of tensile force values demonstrates the variability level of the observed properties at the monitored plot. Values fluctuate significantly on plot No. 2, where heavier soil prevailed. This fact supports the idea of introducing variable applications during tillage. Similarly, the causes for the changes in the values of tensile forces must be investigated further. Because tillage is a mechanical intervention in soil associated with a high energy demand, tillage technologies are subject to a concerted effort to reduce fuel consumption and labour intensity, which is related to achieving favourable costs per unit of production. Precision agriculture technologies are based on information. With the ability to measure tensile force directly with a tractor hitch, we can obtain information about the variability of land without significant additional inputs during machine operation. The map of tensile force, which was measured during ploughing, is in Fig. 5. Only the smallest values and extreme values were removed from the measured data (start and end of working passage).

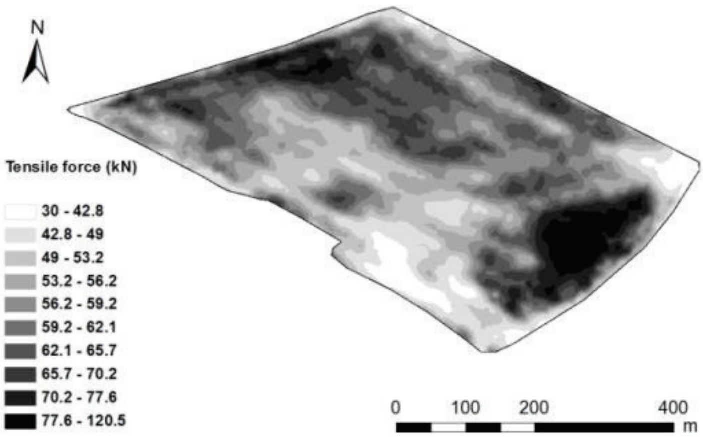

Figure 5. Map of the tensile force measured with a John Deere 8320 tractor.

The results of our measurement revealed possibilities for utilizing components of modern electronic tractors in tensile force measuring.

CONCLUSIONS

Nowadays there are a number of prototypes that allow the continuous measurement of mechanical resistance but the commercial use of these sensors is minimal. In view of the fact that tillage is a mechanical intervention into the soil associated with high energy demands, tillage technologies are subject to a concerted effort to reduce fuel consumption and labour intensity, which is related to achieving favourable costs per unit of production. Current knowledge of tensile force could thus in many respects be a useful tool. The methods of measuring can be commonly used to compare the energy demand of the technologies used for assessing the technical changes in tillage machines or optimizing the tools, and for assessing the agronomic measures implemented on land. In view of management considering the spatial variability of a plot, spatial information on soil properties and their relations to the landscape is needed for the specific application of spatial management. Plenty of important information about the operation of machines could be obtained from the electronics of modern tractors.

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