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Experimental Evaluation of the Soil Pressure Distribution on Plough Parts

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Ploughing is one of the most popular and energy-consuming process among conventional tillage treatments. Ploughing tool is worn down during the interaction with soil. This effect increases the tractor fuel consumption, tillage quality, and maintenance costs due to higher replacement rate of tool parts. In this paper a methodology for the measurement of the pressure distribution generated by the soil on plough components is introduced. Field tests were carried out with a four-furrow plough at different speeds and ploughing depths. Pressure on the different parts of the working body was measured with tactile sensors protected through a suitable PVC layer. The analysis of the results shows that the higher mean pressure values are located on the mouldboard and on the wear plate. Moreover, the vehicle speed affects the mean pressure values and in particular, each part of the plough has a different behaviour. The evaluation of the pressure produced by the soil on ploughs is useful for improving the comprehension of the soil cutting process and consequently to design ploughs with higher wear resistance.

1. Introduction

Ploughing is the most important primary cultivation process used for centuries. Its operation is to cut, shear, crumble, and invert the soil in order to obtain the right conditions for crop growth. But ploughing is also an energy demanding activity and for this reason, many studies have been carried out to improve the efficiency of ploughs by optimizing the geometry with the aim of reducing the required specific draft (Shrestha, Singh, & Gebresenbet, 2001). The optimization was carried out by means of experimental tests and numerical models. Anyway, plough bodies, even though optimized, are subjected to particularly severe wear which lead to a reduced tillage quality, to an increased tractor fuel consumption and maintenance costs due to more frequent part replacements. Indeed, a previous study carried out in Australia demonstrated that tillage wear causes an annual cost of 20 million dollars to Australian farmers for the replacement of ground engaging components (Fielke et al., 1993). Over the last decade many studies were carried out in order to study the most severe conditions for the soil engaging tools in terms of wear and on the materials with higher wear resistance (Er & Par, 2006, Jankauskas, Katinas, Skirkus, & Alekneviciene, 2014). Tillage tool wear is affected by soil texture, soil water content, hardness of the tool material, soil particle shapes, tool operating conditions and soil-tool pressure (Natsis, Papadakis, & Pitsilis, 1999). Soil-tool pressure distribution is a little investigated because it can be hardly modelled or measured. The few numerical studies predicted the pressure distribution through Finite Element Modelling (Mouazen & Neményi, 1999), Discrete Element Modeling (Shmulevich, Asaf, & Rubinstein, 2007; Shmulevich, 2010; Ucgul, Fielke, & Saunders, 2014), Computer Fluid Dynamics (Karmakar & Kushwaha, 2006) and analytical models based on earth pressure theory (Hettiaratchi & Reece, 1967; McKyes, 1985).. The few experimental studies measured the soil pressure through tactile sensors (Mattetti et al., 2017) and strain gauges (Elijah & Weber, 1971). Tactile sensors are more convenient than strain gauges when different ploughs have to be tested due to the simplicity of their installation. Indeed, strain gauge requires a fine surface preparation before their installation and the calibration has to be also carried out on the tool which can be unprecise. From all the theoretical and experimental studies about pressure distribution over tillage tools, it can be concluded that the soil pressure is irregular, increases with the soil shear strength, it is

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quadratically correlated with the speed. Moreover, the highest-pressure area is at the edge and in fact, the edge is the most exposed part to wear.
The aim of this paper is a further investigation on the pressure distribution of the soil pressure over a plough under real working conditions and the evaluation of the combined influence of the speed and ploughing depth.

2. Materials and methods

The tests were performed with a four-furrows plough designed by Nardi (Table 1) towed by a New Holland T7.260 tractor with full-powershift transmission (Table 2) (Figure 1).

Table 1: Specifications and settings of the plough adopted in the test

Type of plough	Double or reversible mouldboard
Number of furrows	4
Connection to the tractor	Mounted
Maximum power required by the tractor [kW]	176
Weight [kg]	1720
Width of cut [m]	2.00
Distance between bodies [m]	1.05

Table 2: Specifications and settings of the plough adopted in the test

Tractor Model	New Holland T7.260
Max engine power [kW]	194
Max torque @1500 rpm [Nm]	1349
Transmission	Full power shift (18 forward, 6 reverse)
Weight with ballast [kg]	8900

Figure 1: The tractor and the plough used during the tests

The agricultural soil on which the tests took place is classified as a silty-clay-loam soil according to USDA Textural Soil Classification (USDA, 1987). Moreover, the plastic limit (PL) is 23% and the liquid limit (LL) is 70%, therefore the plasticity index (PI) is 46%, consequently the soil was classified as a high plasticity clays (ASTM, 2010). The mean value of the soil moisture content (on dry basis) measured during the tests was 22.0% with a standard deviation of 1.3% (ASTM, 2009). The mean value and standard deviation of soil bulk density over the field were respectively 1790 kgm^{-3} and 210 kgm^{-3}. Pressure was measured through ten tactile sensors FlexiForce A201 and FlexiForce HT201 (Tekscan, Inc., USA) were placed on a plough body where high wear spots occur. Whereas the soil has a strong abrasive behaviour, each sensor was protected with a PVC layer glued to the plough with a bi-component epoxy resin. The sensor sensitivities were not influenced by this protection system, in fact the calibration curves were verified after the installation. Even the sensor cables were protected from the soil abrasive action by passing them to the rear part of the tool through dedicated holes created on the plough body. In order to evaluate the tractor speed, a VBOX GPS receiver with an update rate of 10 Hz (Racelogic, USA) was installed on the tractor. The output signals coming from the tactile sensors and the GPS receiver were acquired with NI 9234 modules (National Instruments, USA) plugged to a NI cDAQ 9178 USB data acquisition system (National Instruments, USA). A dedicated program was developed with LabVIEW (National Instruments, USA) to record the acquired data on a PC. Test were made at two different ploughing depths, especially at 0.30 m and 0.35 m. The draught control of the three-point hitch was disabled to avoid any vertical displacement of the plough, so the target ploughing depth remained constant during the test. For each ploughing depth, different average ploughing speed were tested setting different combination of engaged gear and engine load. The target speed during a test was kept constant as far as possible by regulating the engine load depending on the resistant load changes due to the spatial variability of soil properties. In particular, average speeds of 2.0, 3.5, and 5.8 km/h were tested for the 0.3 m ploughing depth, while average speeds of 1.9 and 3.6 were tested for the 0.35 m ploughing depth. For the 0.35 m depth were tested only two speeds because the draft applied by the plough did not permit to plough any faster. Each testing condition was performed for 100 m and repeated three times. The data acquired with tactile sensors with a sampling frequency of 500 Hz were divided by the sensing area of the transducer in order to calculate the pressure applied by the soil on each sensor. Then the pressure mean value over the 100 m of the field test (merging the data of each replies) was calculated for each testing condition. Then, the comparison between the obtained pressure mean values was made plotting the results in a color-bar type plot and calculating the percentage difference between each other.

3. Results and discussion

In Figures 1-5 are reported the pressure mean values acquired in the chosen testing conditions. First of all, the highest mean pressure values were located on the mouldboard (MBL) and on the wear plate (WP) in all the tested conditions. One can note that the mean pressure values obtained at 0.3 m ploughing depth are influenced by the ploughing average speed. Indeed, the mean pressures measured on the mouldboard at 3.5 km/h are significantly higher than those recorded at 2.0 km/h. In fact, MBL1, MBL2 and MBL3 recorded increments in the mean pressure value of 300%, while MBL4 and MBL5 show increments of about 70%. The mean pressure values on the mouldboard acquired at 5.8 km/h are slightly lower than the values measured at 3.5 km/h, MBL1 MBL2 and MBL3 values have a drop of 7%, while MBL4 and MBL5 have a drop around 20%. The tactile sensors mounted on the wear plate show different behaviors with the increasing of speed. WP1 show an increase of the mean pressure of about 30% at 3.5 km/h compared with the value obtained at 2.0 km/h, while WP2 remains constant. Both sensors show a slight variation of the mean pressure value at 5.8 km/h compared with the one acquired at 3.5 km/h especially a decrease of 10% for WP1 and an increase of 10% for WP2. The mean pressure value variation from 2.0 km/h to 3.5 km/h on the plough share (PS) is remarkably high, all the tactile sensors recorded an increment of about 150%. Moreover, the mean pressure values on the plough share acquired at 5.8 km/h are the 30% higher than those measured at 3.5 km/h.

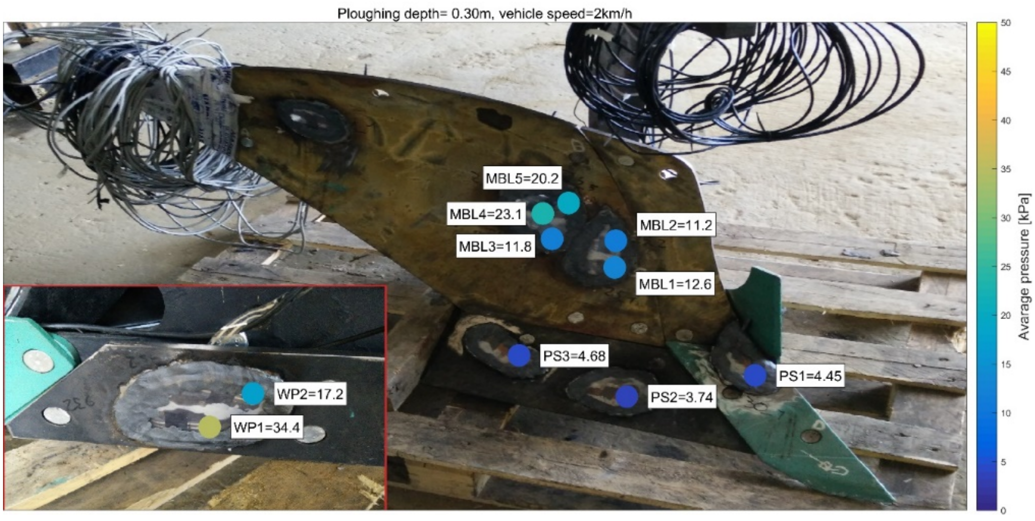

Figure 2: Pressure distribution at 30 cm of ploughing depth and at 2 km/h.

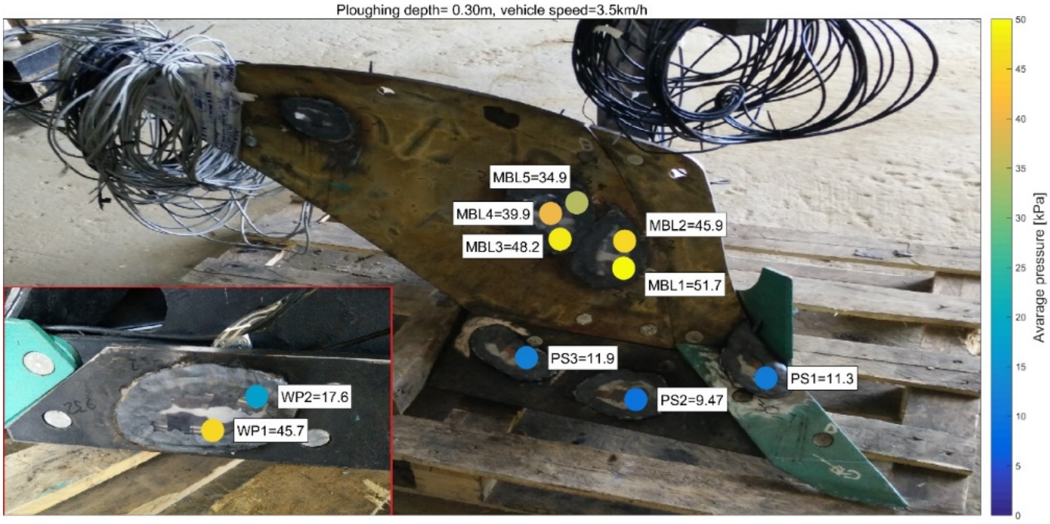

Figure 3: Pressure distribution at 30 cm of ploughing depth and at 3.5 km/h.

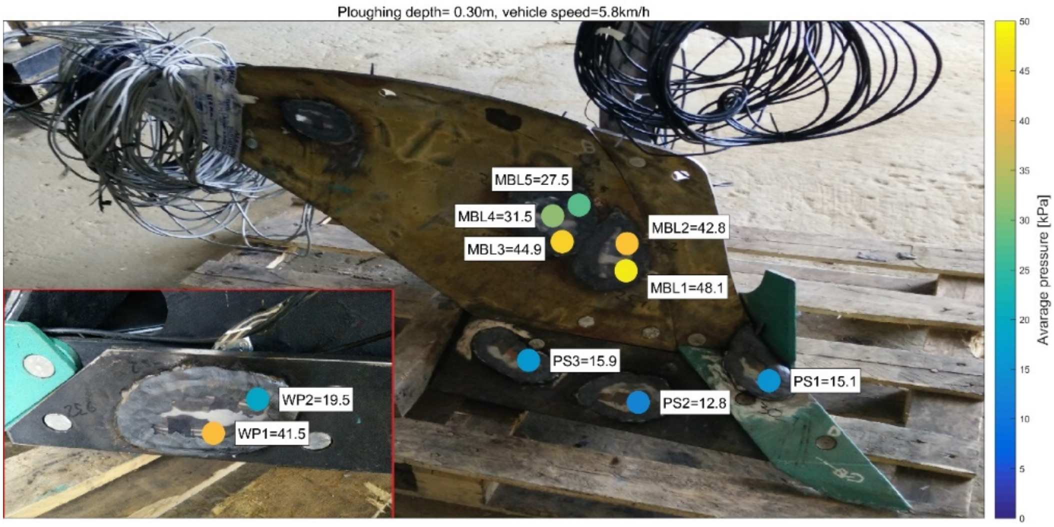

Figure 4: Pressure distribution at 30 cm of ploughing depth and at 5.8 km/h.

The mean pressure values obtained at 0.35 m ploughing depth are influenced by the ploughing average speed only on the mouldboard and on the plough share. The mean pressures measured on MBL1, MBL2 and MBL3 at 3.6 km/h are the 50% higher than those recorded at 1.9 km/h, while the values measured on MBL4 and MBL5 are the 95% higher. The mean pressure value variations from 2.0 km/h to 3.5 km/h on the plough share are similar to those observed for the 0.30 m ploughing depth. In fact, all the tactile sensors recorded an increment of 150%.

Comparing the results obtained with different ploughing depths at almost the same average speed (Figure 3 and Figure 6) one can note that the pressure on the ploughshare doubles with the increase of the depth.

On the other hand, the pressure on the mouldboard significantly decreases with the depth increase, with a drop of the pressures measured by the sensors in the range of 45-71%.

Regarding the wear plate, the sensor WP2 increase with the ploughing depth (+59%), while WP1 remain almost constant.

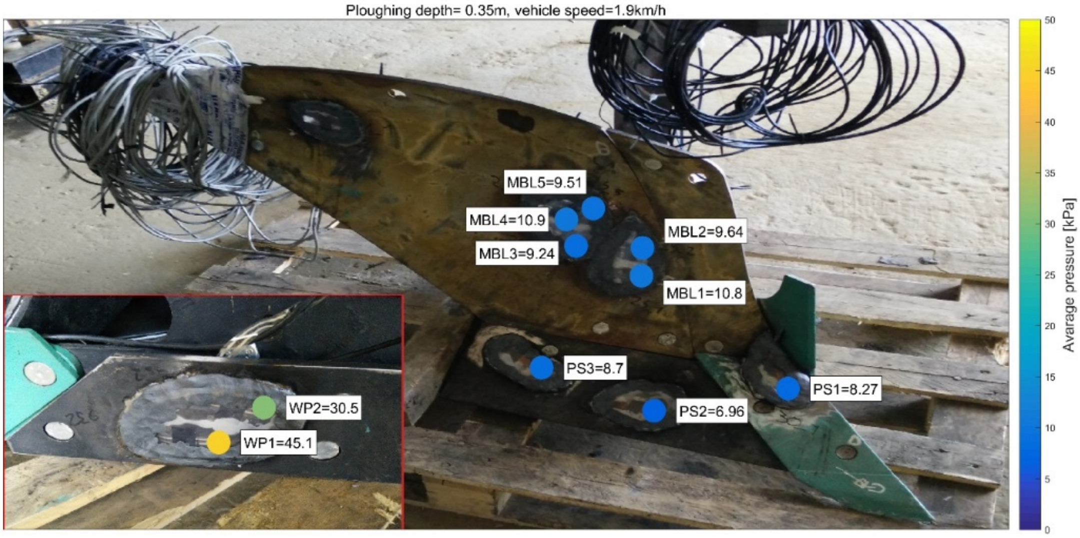

Figure 5: Pressure distribution at 35 cm of ploughing depth and at 1.9 km/h.

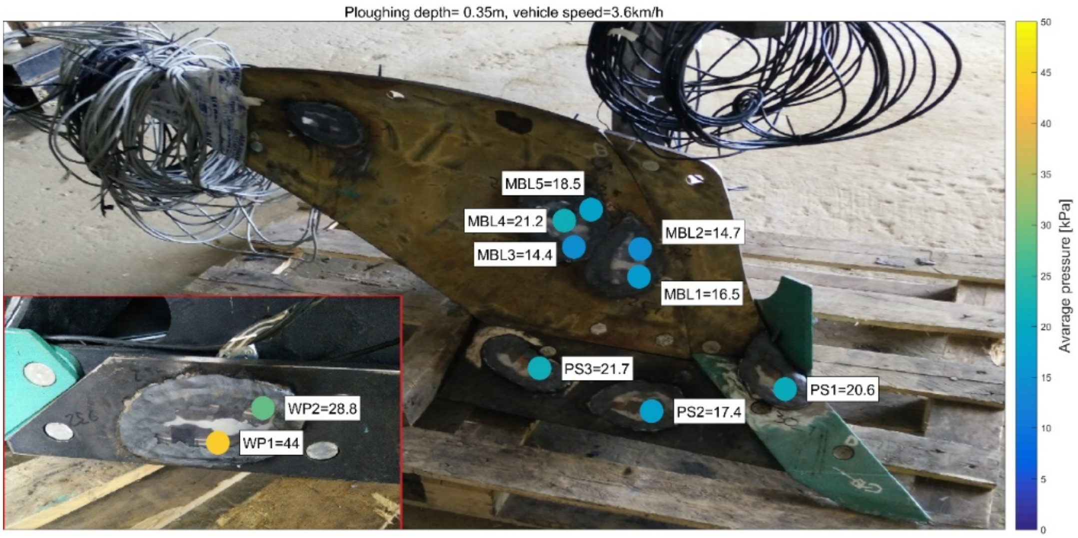

Figure 6: Pressure distribution at 35cm of ploughing depth and at 3.6km/h.

4. Conclusions

In this paper, a test methodology for measuring the soil pressure over a plough was further validated. The data acquired were analysed to evaluate the influence of the combined effect of the speed and ploughing depth on the soil pressure distribution. The analysis of the results shows that the pressure mean values are influenced both by speed and depth, but the effect is different for each part. In fact, the pressures on the mouldboard and on the ploughshare increase significantly with the increment of the average ploughing speed, while the pressure on the wear plate shows a more constant behaviour.

Moreover, maintaining the average ploughing speed constant and increasing the ploughing depth one can note that the pressure on the mouldboard significantly decrease while the pressure on the ploughshare doubles. The methodology and the results introduced in this paper will be useful for the validation of mathematical models able to simulate the ploughing process.

A further development of this work may be the investigation of which soil parameters or conditions affect the pressure/speed relationship and after that the most abrasive conditions for ploughs will be understood.

Thanks to the results of this study, manufacturers will be able to improve the design of their ploughs and farmers will benefit from tools with higher wear resistance.

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