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COMPARATIVE MEASURING OF DRAFT OF SLATTED MOLDBOARD AND MOLDBOARD PLOW WITH A NEW MEASURING SYSTEM

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Abstract

This paper presents the results of research on the draft of two four-furrow plows with moldboard and slatted moldboard, on tilled and untilled soil. Both plows were of the same type and same manufacturer. Same working parameters were used for measuring (depth, working width, speed) so that the slatted moldboard as a factor could be completely excluded.

New device was used for measuring draft of mounted and semi mounted implements of II and III category. The device has a frame with three force transducers for measuring horizontal load on three point hitch of the tractor.

Draft measuring in the field was done with frequency of 10 Hz and 52000 data was obtained during the test. The lowest average value of draft was 19.73 kN measured in the 10th passing on tilled soil with slatted moldboard, and the highest value was measured in the 3rd passing and it was 28.10 kN. Average values of draft and speed for all passings were similar. The results of variance analysis showed that there was statistically significant difference between the mean values of draft of two tested plows, for both treatments, at a confidence level of 95%. Comparison of mean values of draft for slatted moldboard and moldboard plow, for both treatments, showed a difference of 6% in favor of the slatted moldboard plow on untilled soil, and the difference of about 7% was determined on the tilled soil.

Key words: moldboard plow, slatted moldboard plow, draft, measuring, three-point-hitch frame

Introduction

Soil tillage is the most efficient way of improving physical properties of soil and, in conventional tillage, this is performed evenly over the entire surface by a moldboard plow (Siefken et al., 2005) which significantly reduces the presence of weed and other pests on the plot. In the technological chain of field crops production, soil tillage is the most energy consuming activity which implies that, with high fuel price, the possibilities of reduction of fuel consumption should be considered seriously. One of the options is certainly the acquisition of machinery which would generate minimal costs and offer maximum quality for a given size of land, type of soil, structure of production, etc. In that sense, farmers have become increasingly interested in this issue but they are still unable to decide due to the lack of information. Wrong decision in acquiring machinery can have huge negative effect on both fixed and variable expenses (Grisso et al., 1996). In order to make the right choice of tillage machinery it is necessary to have enough information about drafts for certain types of soil (Alimardani et al., 2008; Al-Janobi et al., 1998). Currently, farmers in Serbia do not have such information available so they rely on their experience and intuition. Development of new implements with increased working width and speeds makes farmers' knowledge and experience of little or no use. Measuring of draft for specific soil conditions is important for the assessment of an agricultural machine (Naderloo et al., 2009). Measuring of draft of different implements provides useful information on power requirements for different tillage and different management systems in field (Perfect et al., 1997). Research performed by numerous authors successfully determined the consumption of energy based on draft force. Energy savings with changeable tillage reach up to 42.8%, i.e. 28.4% of fuel (Gorucu et al., 2001). Data available on implement draft during tillage in different soil conditions can help farmers make rational choices about tractors and tillage machines and their efficient exploitation (Alimardani et al., 2008; Kheiralla et al., 2003; Onwualu et al., 1998; Sahu et al., 2006).This measuring can also help to understand better soil-implement interaction (Upadhyaya et al., 1987; Owen et al., 1990).

One of the methods to increase field efficiency of a tillage machine is to increase its capacity. In order to achieve this it is necessary to increase the working speed. However, main problem in soil tillage with a moldboard plow at higher working speeds is high draft which increases exponentially with increased speed. Hunt (1973) showed that draft of moldboard plow at speed of 20 km/h was 150% bigger than at speed of 5 km/h. Research made by Iowa State University indicated that dependence of plow draft on the working speed is not universal for all types of moldboards (Eidet, 1974).

Numerous authors are focused on determining the draft of moldboard plow. Most of them got the results which showed that draft was square function of working speed (Gill and Vanden Berg, 1968; Kepner et al,. 1982; Goryachkin, 1968; Godwin, 2007). Up to now, the described mathematical models, which are used to estimate the draft of moldboard plow of tillage machines, cannot predict precisely the intensity of draft due to complex interaction of a machine and soil. The most commonly used equation for validation of the values obtained for draft of moldboard plow is in accordance with ASAE standard (ASAE D497.6):

$$D = F_i \, [A + B\,(S) + C\,(S)^2]W \times T \qquad (1)$$

where *D* is horizontal draft force, *F* is the parameter related to soil texture, *A*, *B*, and *C* are specific parameters for tool (for moldboard plow A = 652, B = 0, C = 5.1). *S* is forward speed of tractor, *T* is width, *W* is working depth of implement.

Two types of dynamometers are used for measuring draft in field tests: towed dynamometers and three-point-hitch dynamometers. Towed dynamometers are used for measuring draft at one point and they are usually used on towed machinery or mounted and semi-mounted machinery, but with use of an additional tractor for towing machines (Naderloo et al., 2009). These dynamometers have long been a subject of research of numerous authors (Godwin, 1975; Zoerb, 1983; Godwin et al., 1993; Kirisci et al., 1993; Chen, 2007). The second category of a measuring system represents the measuring frames attached between a tractor and its implement. The frame is a measuring element with force transducers and it is attached between a tractor and its implement (Kheiralla et al., 2003; Askari et al., 2011; Alimardani et al., 2008; Sholtz, 1966). The advantage of measuring draft force with a frame is that it can easily be divided into horizontal, vertical and lateral force. Also, it can be used on different types of tractors and implements. Disadvantages of this type of measuring are the increase in total weight and different geometry of the system.

The aim of this paper was to test the drafts of two identical plows, with moldboard and slatted moldboard, and determine their influence on total drafts.

Material and method

A new three point hitch measuring device (Figure 1) was used in this research. The device was intended for the measuring of draft force of tillage implements that can be mounted, semi-mounted and towed. Lateral forces were not measured because they are insignificant under normal working conditions, that is, when an implement is properly attached. According to the above given classification this device belongs to a category of frames that are equipped with force transducers and placed between a tractor and an implement. The frame was designed in AutoDesk Inventor 2012. The implement was installed 692 mm back from tractor three-point-hitch. The frame mass, together with the measuring elements, was 125 kg. Vertical eccentricity of front lower link points with respect to the rear lower link points was 116 mm. Structure of the frame enables its attachment to tractors and implements of II and III category in accordance with ASAE standard [38].

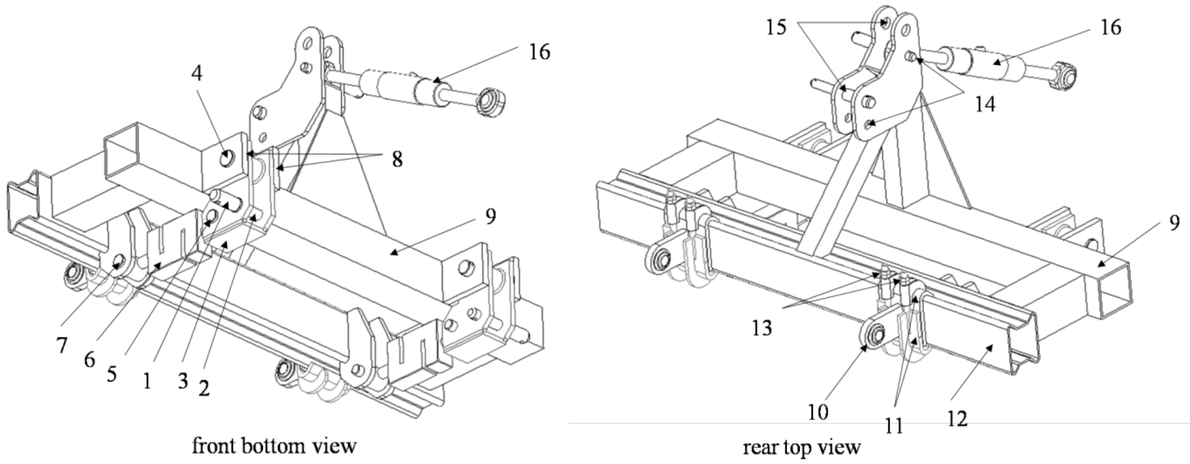

Figure 1. Three-point hitch frame for draft measurement:1, 2-lower link to tractor; 3-console; 4, 5, 7-pin;6-force transducer; 8-side plate; 9-square shaped beam; 10-lower link to implement; 11-decomposable clamp; 12-profile beam; 13-screws; 14-upper link II cat.;15- upper link III cat.;16-top link force transducer

The device is a frame with front and rear three point hitches for II and III category of tractor and implements. Lower points for connection of the frame with tractor 1, 2 are pins with changeable cross section. Exterior, wider part 1 is envisaged for the connection with III category tractors. Interior, narrower part 2 is envisaged for the connection with II category tractors. The pins are fixed onto the consoles 3. Consoles 3 are connected to the frame structure by pin 4 directly and by pin 5 indirectly, i.e. measuring cells 6 and pin 7. Pins 4 and 5 eliminate the possibility of free vertical movement of the console, and the side plates 8 welded to the front square shaped beam 9, block horizontal movement. Stiffening of lower points that link the frame with tractor enables simultaneous lifting of a machine and frame without any additional protection measures which would protect the force transducers from overload which is possible in case of transport of heavy machinery. Figure 1 (cross section, view A-A) shows that the points of connection of the frame to tractor 1 and 2 are in the same horizontal plain as well as the pins 5 and 7, and axis of measuring cells 6. This kinematic connection transfers all horizontal draft force in link points 1 and 2 to the measuring cell 6 which implies that the detected force in measuring cells 6 represents the actual value of draft force.

Lower links for implement attachment to the frame 10 are designed as the ends of the lifting lever for tractor with spherical elbows that have adequate diameter of the opening. Two sets of rear lower levers for connection to the machinery of II and III category are envisaged. They are located on the decomposable clamps 11. The clamps are fitted to the beam 12 where they can move crosswise and, when necessary, be replaced in order to adjust to the structure of the II and III category implements. The clamps 11 are fixed with screws 13. Upper points of connections of machine with the frame, and frame with the tractor have two openings, one link 14 for II category and one link 15 for III category. The top link lever for connecting tractor with frame is a standard dynamometer which measures the load in the upper point of connection. The length of a top link lever-dynamometer can always be changed with a leadscrew.

Sensors and data aquisition

Lower link force transducers were of „S“ type, 100 kN capacity, 0.1 N resolution and accuracy of ±0.5% , and tractor top link force transducer had a capacity of 200 kN, 0.1 N resolution and ±0.5% accuracy. Force transducers were connected to a general purpose measuring amplifier/ system for data acquisition (HBM-MX440A). Measuring acquisition was high resolution acquisition (24bit) with possibility of adjustment of sampling speed (to 19200 Hz). Data acquisition and a PC had Ethernet connection.

GPS device Trimble EasyGuide 500 (EGNOS/WAAS) was used for measuring speed and determining geographical position of tractor and its imlement, and the device had standard external port RS232 for communication and data transfer to PC. The GPS reading frequency was 10 Hz (maximum).The frequency was adjusted to 10 Hz during the test. In order to reduce the high frequency variations of short-range force Bassel’s filter was used for eliminating the signals of more than 2 Hz frequency from force trasducers.

a) b)

Figure 2. Data acquisition equipment in the tractor cab: a- DAQ device; b-GPS reciever and Laptop data logger

Field test

Filed experiment was conducted in November, 2012 in the Province of Vojvodina, North Serbia (19.1^0 E, 45.4^0 N). The test was performed on an area of 1.12 ha. The type of soil was humoglei. Forecrop on the plot was soybean that was grown conventionally. Measuring was done on untilled and tilled soil. After forecrop removal the tillage was performed at depth of 35 cm. Tillage gave one new additional variant of soil physical condition with neutralized local specificities. Untilled field was named ‘’plot A”, and tilled field was named “plot B”; the moldboard plow was marked „MP“, and slatted moldboard plow was marked „SMP“. Soil condition was evaluated using the samples from randomly chosen locations on the plot. The samples were used for determining average texture and moisture. Moisture of the taken samples was determined by a method of drying in the drier at 105^0C for 24 h. In the „plot A“ it was 19.3%, and in the „plot B“ it was 17.3%. Electronic penetrometer made by *Finland, Irvine Ltd.* was used for determining the level of soil compaction. The penetrometer had a diameter of 12.83 mm in the cone base and an angle of 30^0 which is in accordance with the ASAE Standard (ASAE S313.3). The speed of cone penetration into soil was 35 mm/s and reading of draft was done at every 3.5 cm. Diagram of soil compaction presented in layers can be seen in Figure 3.

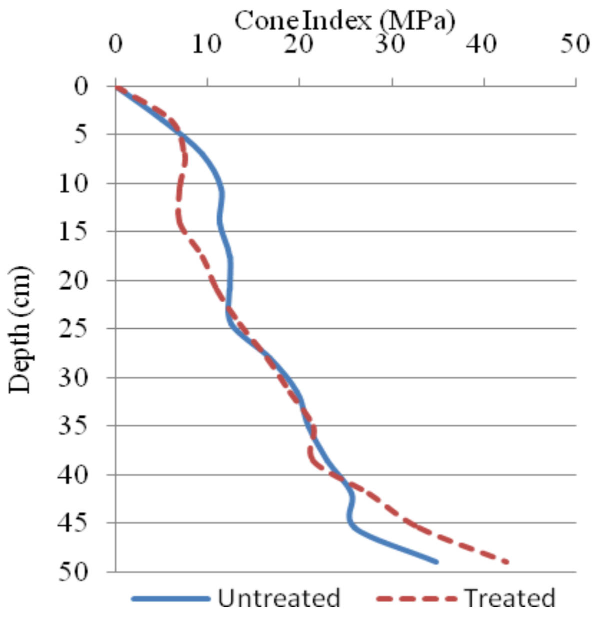

Figure 3. Cone penetration field data

John Deere 6930 tractor was used in the field test. It had engine power of 98kW and two four-bottom moldboard plows of the same type, manufacturer and form of universal body, but the one was equipped with slatted moldboard and the other with moldboard (Figure 4). The working speed can be adjusted within a range of 1.44-1.92 m. Both plows were operated at same working parameters which were constant during the test so that the effect of each universal body could be assessed for drafts. The average depth achieved by both plows was 0.25±0.03 m, and the working width was 1.47±0.08 m. Some authors indicated that uncontrolled variations in the working width of the first body, especially if it is a multi-furrow plow, does not affect the draft significantly (Van Bergeijk et al., 2001). The control of tillage depth and working width was done in every passing in ten replications. The tillage depth of rear universal body was limited by land wheel. The speeds achieved during measuring for both treatments are given in Table 1.

Table 1. Achieved working speeds during test

	GPS speed (m/s)			
	Plot A		Plot B	
	MP	SPM	MP	SPM
Min	1.16	1.32	1.57	1.53
Max	2.16	2.09	2.57	2.34
Mean	1.76	1.71	2.24	2.06
STD	0.16	0.15	0.16	0.17

The hypothesis of the experiment was based on the possibility that if we towed the implement through soil at constant depth, working width and speed, average draft would depend on the design of universal bodies of the plow and local variations in soil physical properties. Both plows were equipped with new moldboards in order to avoid negative effect of uneven bluntness of the blades on the final result of the test.

Figure 4. Draft measuring system (tractor+three-point-hitch device) and tested plow (slatted moldboard plow)

Data analysis

Data were collected during the test and stored on a PC with data collection software (HBM-CatmanEasy-AP3.4.1.). The first step was to eliminate the data collected at the moment of aggregate's turning (at the end of the plot) as well as the data collected at the beginning of the passing until stable work parameters (speed, working depth) were reached. Also, errors from GPS receiver resulting from signal interferences were eliminated. By eliminating the atypical values, signals for individual neighboring passings were obtained.

Total draft force was calculated by adding the values obtained from lower force transducers with corrected top-link values. Value of tractor top link force was corrected in accordance with the angle that was covering top-link with surface during measuring. Considering that the speed of tillage is impossible to keep absolutely constant (due to wheel slippage and abrupt change of draft) a correction of draft was made for standardized velocity. Since the speed varied in narrow intervals, linear pattern was used (2) simple correction of draft values. Correction factor was 5 kN m^{-2} for every 1 m s^{-1} of speed increase. Referential speed was determined based on the average speed during the test, and it was 1.8 m s^{-1}:

$$F=F_0+(5.0*1.8) \quad (2)$$

where: F_0 is the specific plow draft in kN/m^2 at a velocity v_0 of 1.8 m/s; F is the specific plow draft in kN/m^2 at velocity v; and v is the actual velocity in m/s.

Statgraphics Centurion XV.I. software was used for data processing.

Results and discussion

Draft measuring in the field was performed at frequency of 10 Hz and around 52000 data was obtained during the test.

Results of draft with respect to the type of moldboard for both plots are given in Table 2 as mean value ± standard deviation (Mean±SD), coefficient of variation (CV) and minimal (maximal) achieved values.

The lowest average value of draft was 19.73 kN and it was measured in the 10th passing on tilled soil with slatted moldboard, and the highest value, 28.10 kN, was measured in the 3rd passing. Average values of draft and speed were similar for all passings. Standard deviation was the highest in the 6th passing (3.29 kN), while all other passings showed similarities in this parameter. As regards the speed, more similarity was observed in the mean values and standard deviation in passings.

Table 2. The test results of draft

Passing	Plow	Plot	Mean±STD	Min	Max	CV
1	MP	A	27.04±2.73	10.68	32.98	17.89
2	MP	A	27.84±2.60	15.55	36.92	18.10
3	MP	A	28.10±3.10	10.63	32.79	19.93
4	MP	B	21.35±2.11	14.35	24.92	20.86
5	MP	B	21.66±2.62	10.96	26.73	24.22
6	MP	B	22.95±3.29	8.04	40.16	25.36
7	SMP	A	27.41±2.40	14.80	27.19	13.29
8	SMP	A	24.86±2.74	6.99	32.19	18.98
9	SMP	A	26.16±2.49	13.80	27.50	15.41
10	SMP	B	19.73±2.08	12.54	22.76	19.44
11	SMP	B	21.16±1.90	14.21	17.94	15.69
12	SMP	B	20.82±2.10	12.25	24.44	16.94

Still, big differences between minimal and maximal values of draft force in passings imply significant changes on the draft amplitude in time (Hayhoe et al., 2002, which can be easily observed on the graph (Figure 5).

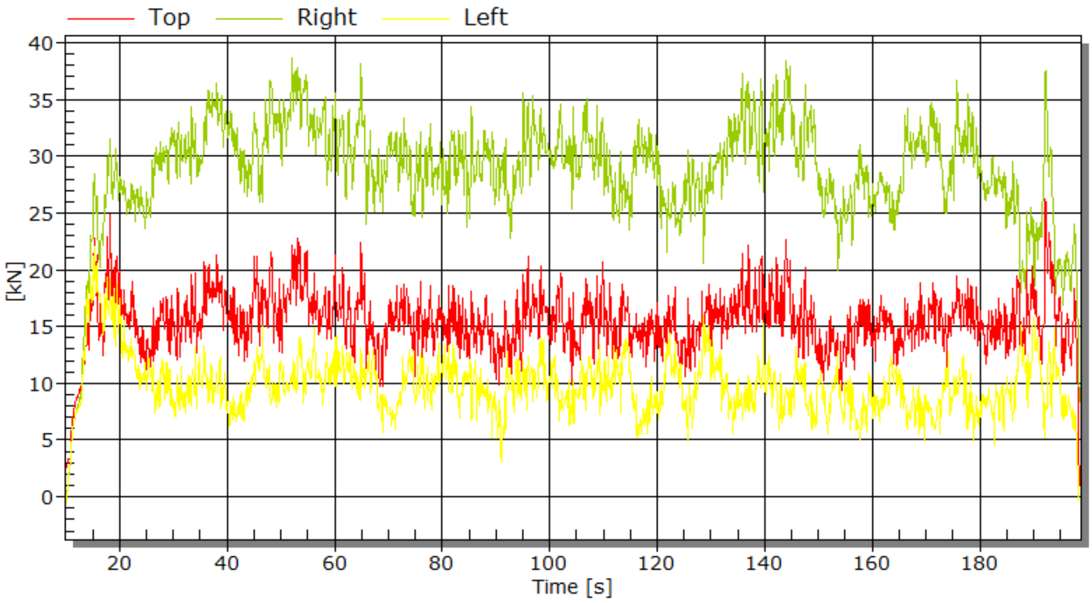

Figure 5. Real-time graph of recorded draft force for one passing

Table 3. Analysis of Variance for draft force

Source	*Sum of Squares*	*Draft force*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:Moldboard type	6.45333	1	6.45333	8.04	0.0219
B:Plot	94.8656	1	94.8656	118.24	0.0000
INTERACTIONS					
AB	0.0075	1	0.0075	0.01	0.9254
RESIDUAL	6.41833	8	0.802292		
TOTAL	107.745	11			

The results of variance analysis showed that there was statistically significant difference between the mean values of draft of two tested plows, for both treatments, and for the level of confidence of 95%. Table 3 shows that in this case the soil was more important factor for draft than the type of moldboard.

Figure 6 shows diagram of interaction of this type of moldboard and soil pre-treatment and its effect on the draft. It is clearly seen that on both types of soil moldboard has bigger draft than the slatted moldboard, which was expected considering the smaller contact area in case of slatted moldboard and less friction between soil and moldboard.

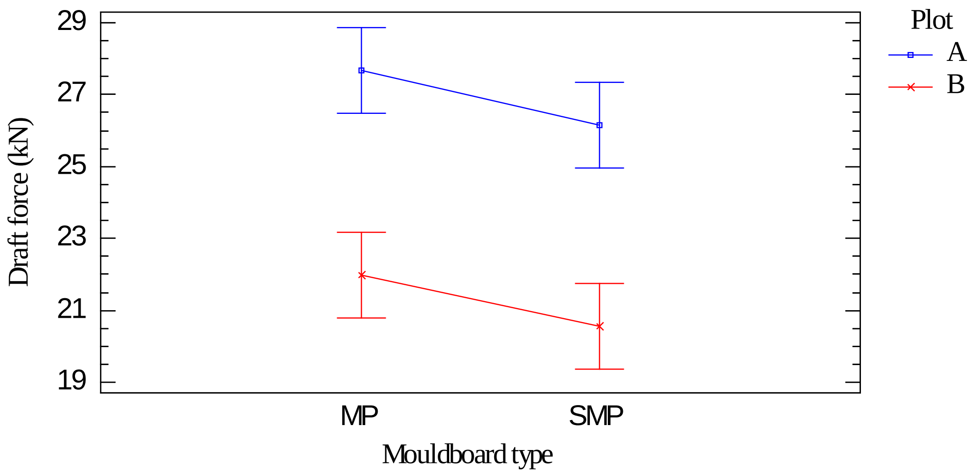

Figure 6. Interaction of type of moldboard and soil and its effect on the draft

By comparing the mean values of drafts of moldboard and slatted moldboard, for both treatments, a difference of 6% was observed in favor of the slatted moldboard on untilled soil, while the difference on tilled soil was on average about 7%. These results confirm the difference between slatted moldboard plow and moldboard plow of similar dimensions on tilled and untilled soil, which confirms the hypothesis that draft depends not only on the physical properties of soil and working parameters, but on the design of tool elements as well (Askari et al. 2013; Al-Janobi et al. 1998).

Conclusion

The following conclusions could be drawn according to the results of measuring the draft of moldboard plow and slatted moldboard:

- the measuring equipment used in the test met all the requirements,
- the values obtained for the draft of both types of plow were within the expected range,
- mean values of draft in passings were similar which confirmed stability and reliability of the measuring system,
- the measuring system is extremely sensitive and is able to detect the slightest changes of draft in time,
- difference between the draft of slatted moldboard and moldboard plow on untilled soil was 6% in favor of the slatted moldboard, and 7% on the tilled soil.

In order to come to more reliable conclusions about the influence of the design of moldboard on the draft, it is important to:

- repeat the measuring on different types of soil,
- measure the draft at different working speeds,
- consider the intensity of soil crushing (size of the aggregate).

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