

Influence of top link length of three-point hitch on performance parameters of ploughing set

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Abstract

ČUPERA J., ŠMERDA T., 2010. **Influence of top link length of three-point hitch on performance parameters of ploughing set.** Res. Agr. Eng., 56: 107–115.

The target of the realized measurement was to subject the influence of top link on wheel slip and performance and economic parameters of ploughing set. To meet the objectives the set of New Holland 7050 tractor aggregated with plough Kuhn Variomaster 150 was used during field work. Parameters of internal systems were monitored via CAN-Bus, e.g. engine speed, fuel consumption, fuel temperature, atmospheric pressure, intake air temperature, time of trip, etc. Additional external measurement consisted of a signal of rear wheels rotation and signal of radar sensor for slip determination. Load cell sensor HBM was mounted into a top link. The values of slip were reduced when the top link length decreased. A change of wheel slip from 16.6% to 11.2% caused by reduction in length brought improvement in performance up to 16.5% and effective fuel consumption per hectare lowered about 18.1%.

Keywords: fuel consumption; wheel slip; ploughing set; tractor

Energy needs of agricultural production will lead to put continuously pressure on fuel consumption reduction, which will push manufacturers and its operators to search for potential savings. In the case of tractors, the ways exist to improve the efficiency of conversion of mechanical energy to useful work, either by increasing the contact area or weight and their adaptation to the current conditions. The issues of improving the efficiency of power transfer to the surface were researched by many authors (FORREST 1954; ABEELS 1976; BURT, BAILEY 1982; BLOOME et al. 1983; DWYER 1984; CORCORAN, GOVE 1985; ZOZ, TURNER 1994; ZOZ et al. 2002) the results confirmed the positive benefits of increasing contact area and weight to fuel consumption reduction. Manufacturers fit tractors with precise regulation systems, which aim to reduce driver's effort and especially fuel consumption, for example by

keeping the engine speed in area of the highest efficiency, hydraulic regulation, load sensing, control the fan speed, etc. (RENIUS 1994). Very important part of the task is also to correct aggregation together with optimal adjustment of connected machines. One of the first producers of agricultural equipment that reacted to efforts to reduce energy needs of agricultural work was the Lemken GmbH & Co. KG; they presented a hybrid plough VariTansanit at the Agritechnica 2005 in Hannover. This plough is characterized as carried in the aggregation and transfers a part of weight attributable to depth wheel to the tractor. This technique requires a top link hydraulically controlled. As a result of this wheel slip reduces and improves efficiency of fuel energy. The aim was to assess the influence of changes in length of top link on wheel slip and performance-economic parameters of ploughing set.

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. COST 356 OC191 and by the Mendel University in Brno, Project No. IGA 2010 TP3/2010.

Table 1. Specification of a set

Measured parameter	Method of measurement
Engine speed, fuel consumption, fuel temperature, engine load, engine coolant temperature	CAN-Bus
Actual velocity	radar sensor RDS TGSS
Theoretical velocity	incremental optical sensor with 360 pulses per revolution
Force in top link	load Cell HBM Hottinger U2A, max. force 100 kN
Working width	measured according to ON 470166, at a distance of 10 m from the outer wall of furrow 20 rods were placed and after run the difference was measured
Working depth	measured according to ON 470169 in the same places as mentioned in “working width”, measured by depth gauge

MATERIALS AND METHODS

To realize the objectives, the tractor NH 7050 with carrier-mounted plough Kuhn Variomaster 150 was used. Technical specifications are given in Table 1. Measurements were carried out on sandy-loamy soil with mass moisture 14–16%. One measurement consisted of four runs with a total distance of 1,200 m. Parameters of internal systems were monitored via CAN-Bus, e.g. engine speed, fuel consumption, fuel temperature, atmospheric pressure, intake air temperature, time of trip, etc. Additional external measurement consisted of a signal of rear wheels rotation and signal of radar sensor for slip determination. Load cell sensor HBM was mounted into a top link. Adjustment of top link is given in Table 2.

Top link was mounted through the top oval hole via pin to frame of hitch (Fig. 1). The frequency of sampling was 20 Hz. Furthermore, depth and width of furrow were measured after each run. Slip was also calculated from the distance after five revolutions of the



Fig. 1. Connection of top link with inserted load cell

front and rear wheels. Zero slip was assigned within lifted plough when tractor drove in the furrow.

Measuring system consists of two distributed applications combining analog and digital channels (Fig. 2). Analog signal presents drawbar pull or signal of load cell U2A HBM with a range of 100 kN. Load cell amplifier HBM Spider8 was connected via LPT port to a measuring notebook. The amplifier includes precise source of excitation and signal is processed by ADC with 16-bit resolution. The actual velocity of the tractor was measured using the frequency output of an external radar sensor TGSS RDS that has the characteristic parameter of pulses 128.52 per m. To determine the wheel slip, it was also necessary to know the theoretical speed of the wheel. Incremental optical sensor (IRC) with 360 points per revolution was used for this purpose. The second part of the measuring system saved the data from the CAN-Bus. A communication card from the National Instruments (NI PCMCIA CAN Series 2) was inserted into the notebook. This card is fully compatible with requirements according to SAE and ISO 11 989 standards. The synchronization between parts of measuring chain was essential. To meet this target it was necessary to write own measuring application. For this purposes native development system called LabView was used. The main loop timing was set to 20 samples/s as well as data logging. The programming project was built as three independent routines. The first loop asked library (DLL) released by HBM company and used inner functions. This routine ran at 100 samples/s and the resulting value was based on average of five points. The second loop was in charge of CAN-Bus monitoring. Communication speed of CAN-Bus was 250 kbps. Because architecture

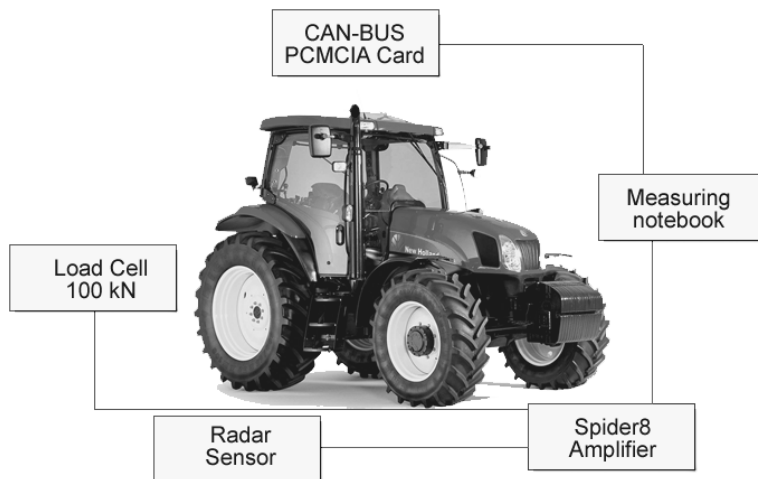


Fig. 2. Field instrumentation of tractor’s parameter measurement

of CAN-Bus, which is based on events and some of parameters cannot be achieved more frequently than every 50 ms, the value was repeated until its change. The third loop had a task to store data to a file. Generated file contained data in ASCII format due to simplicity of import into various spreadsheet editors, e.g. MS Excel, etc.

All measurements were made with a full supply of fuel and the differentials were locked at both axles. Adjustments of the length of the top link and regulation of three-point hitch in the individual tests are given in Table 2.

Before the measurements the tractor itself and the whole set were weighed. The results are given in Table 3.

From the measured values the following parameters were calculated:

Working width

$$B = \frac{\sum_{i=1}^n b_i}{n} \text{ (m)} \tag{1}$$

where:

n – number of measurements (–)

b_i – i^{th} measurement of plough working width (m)

Working dept

$$h = \frac{\sum_{i=1}^n h_i}{n} \text{ (m)} \tag{2}$$

where:

n – number of measurements (–)

h_i – i^{th} measurement of plough working depth (m)

Effective performance

$$W_1 = \frac{S}{T_1} \text{ (ha/h)} \tag{3}$$

where :

S – ploughed surface (m²)

T_1 – main time (h)

Table 2. Length adjustments of top link, settings of hydraulic regulation, and engine speed

No. of measurements	Top link length (mm)	Type of regulation	Shifting mode	Engine speed
7	810	position	manual	1,900–2,100 1/min
8	790	position	manual	1,900–2,100 1/min
9	770	position	manual	1,900–2,100 1/min
10	765	position	manual	1,900–2,100 1/min
11	765	draft	manual	1,900–2,100 1/min
12	765	position	manual	1,600–1,800 1/min
13	765	position	manual	1,600–1,800 1/min

Table 3. Weight (kg), fuel tank filled to 50%

Tractor itself	
Rear axle	4,400
Front axle	4,160
Total weight	8,560
Ploughing set, plough in transport position	
Rear axle	8,320
Front axle	1,860
Total weight	10,180
Ploughing set, plough above the ground	
Rear axle	8,420
Front axle	1,760
Total weight	10,180

$$\delta_2 = \left(\frac{l_t - l_s}{l_t} \right) \times 100 \quad (\%) \quad (9)$$

where:

δ_1 – wheel slip of front axle

δ_2 – wheel slip of rear axle

l_t – real track distance (m)

l_s – number of wheel revolutions during ploughing of one plot (–)

Specific effective performance

$$W_{1m} = \frac{S \times h}{T_1 \times 0.36} \quad (\text{m}^3/\text{s}) \quad (4)$$

where :

S – plowed surface (m²)

T_1 – main time (h)

h – depth of ploughing

Average fuel consumption

$$\bar{Q} = \frac{\sum_{i=1}^n q_i}{T_1 \times f} \quad (\text{l/h}) \quad (5)$$

where :

q_i – actual fuel consumption (l/h)

f – sampling

The volume of fuel consumed at one measurement

$$Q = \bar{Q} \times T_1 \quad (\text{l}) \quad (6)$$

Effective specific fuel consumption

$$\bar{Q}_{1m} = \frac{Q}{S \times h \times 10^3} \quad (\text{ml/m}^3) \quad (7)$$

Wheel slip

$$\delta_1 = \left(\frac{l_t - l_s}{l_t} \right) \times 100 \quad (\%) \quad (8)$$

The measured and calculated values were processed and evaluated using the Microsoft Excel spreadsheet editor. On the basis of the obtained results effective and operative parameters were calculated: fuel consumption per hectare, effective specific fuel consumption, performance and dependence of force in top link on wheel slip.

Variation coefficients were calculated for averaged values of working width and depth. Their size ranged from 0.9–9.43%. For dependence $\delta = f(F)$ the linear regression function with a coefficient of determination 0.9 was used.

RESULTS AND DISCUSSION

The aim of the measurements was to assess the impact of the length of the top link on performance-economic parameters of a ploughing set consisted of New Holland 7050 tractor and carrier-mounted plough Kuhn Variomaster 150. To meet the targets 21 measurements were performed in which the length of the top link was decreased from 805–765 mm. Both types of regulation of three-point hitch, draft and positioning, were used within effort to keep engine speed by manual shifting in a range from 1,900–2,100 1/min. On the basis of the obtained results effective and operative parameters were calculated: fuel consumption per hectare, effective specific fuel consumption and performance; they are listed in Table 4 and in Figs 3–6. The courses of pull force and fuel consumption during ploughing are shown in Fig. 8a, b, c. The force applied in the top link of hitch has an impact on the rate of torque in the contact area of rear tires and surface of the ground. If the pull force applied in the top link is higher, it will then transfer a part of weight of plough on tractor chassis. The wheel slip was decreased with the reduction in the length of the top link (Fig. 7), e.g. average value of slip reached to 16.6% during the seventh measurement, whereas in the tenth measurement the

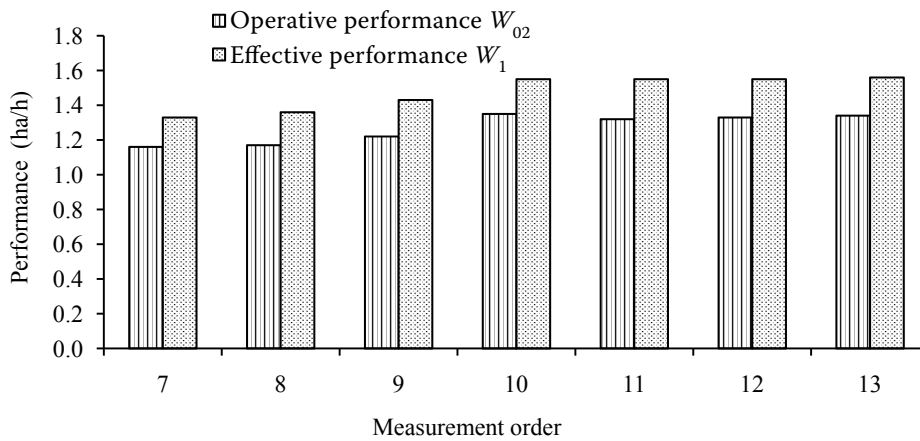


Fig. 3. Performance of ploughing set

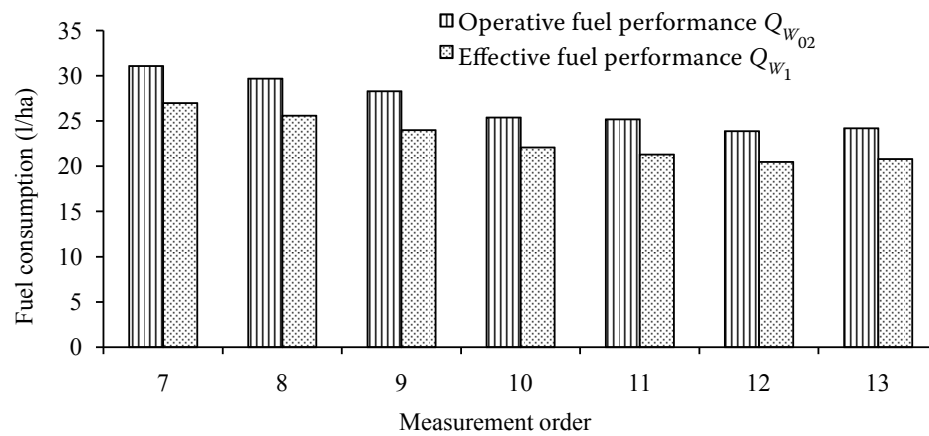


Fig. 4. Fuel consumption of ploughing set per hectare

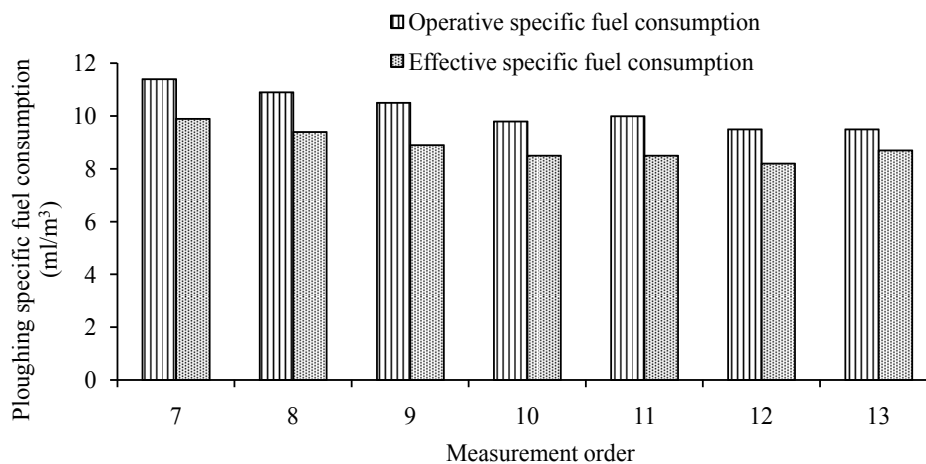


Fig. 5. Ploughing specific fuel consumption

slip achieved 11.2%. Similar results were obtained in the Research Institute FAL (Forschungsanstalt für Landwirtschaft) in Braunschweig, where the testing

was carried out with a similar four-body plough, in the reduction of slip from 19–10% at the maximum force in the top link (OBERHAUS, MILLER 2005). The

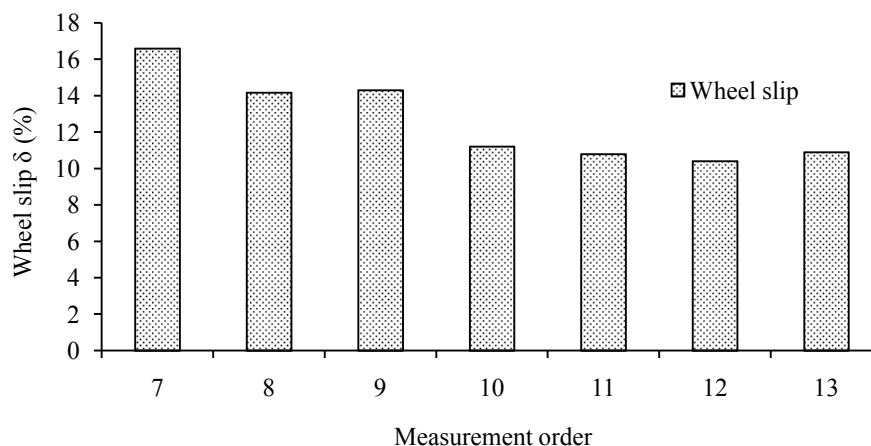


Fig. 6. Average wheel slip at ploughing

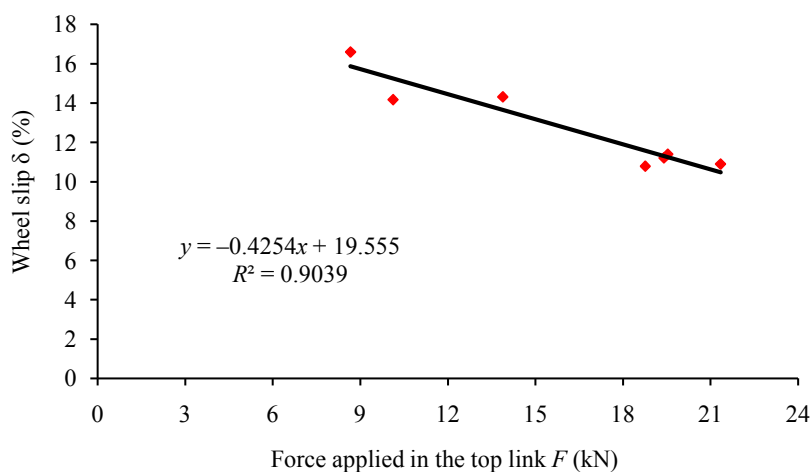


Fig. 7. Wheel slip dependence on force in top link of three-point hitch

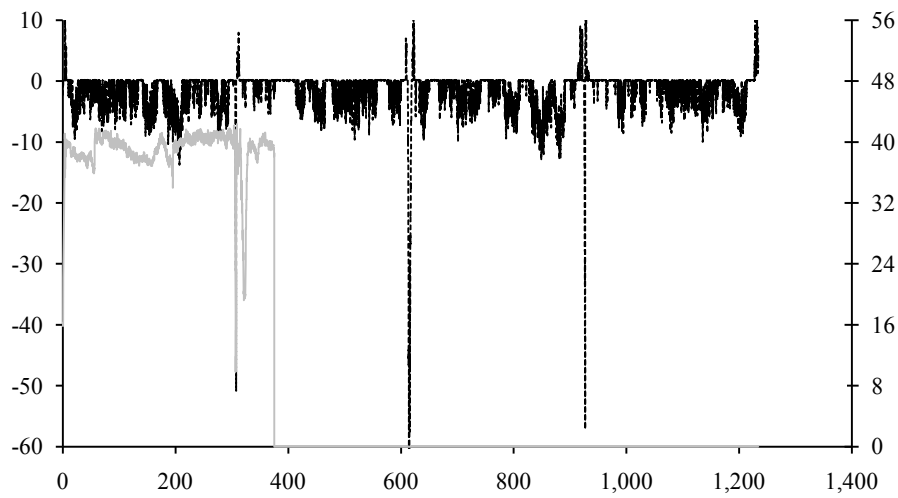
same issue was also observed by HESSE and MÖLLER (1974), who also reported a reduction in wheel slip when the force in the top link grew up.

The disadvantage of increasing force may be reduction of sensitivity of the regulation mechanism in the case that the force impulse is transferred through top link. Similar measurements were carried out by AHOKAS (1996), who reported that when depth wheel was used, wheel slip ranged from 7–9%. In the case without the use of depth wheel the wheel slip achieved a value between 10% and 11%; this applies to rear axle drive. Moreover, he also drew attention to the larger variability of depth of ploughing, which increased by 13% without depth wheel. In the case of our measurements the coefficient of variation of depth was up to 10%, which was in the tolerance described by many authors (SKALWEIT 1952; DWYER 1984), however, e.g. DWYER et al. (1974) expanded the discussion of tolerance of 10%, as there is no ag-

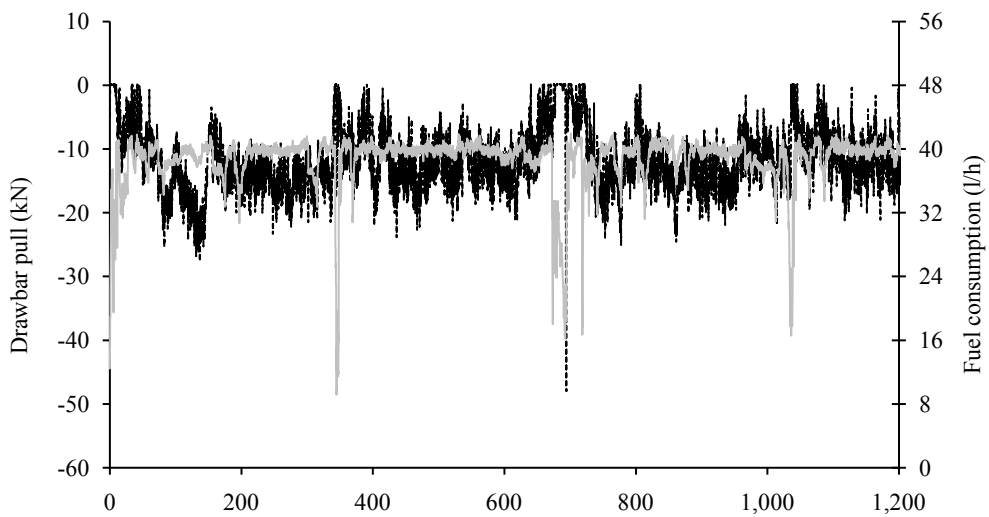
ronomic reason why the variability of depth could not be greater. If the wheel slip lies in the optimal range of working width, then the effort to slip reduction will lead to an increase in running speed; with regard to the wheel slip in optimal range of depth from 0.3–0.5, the effort to its reduction leads to an increase of running speed, as well.

This fact was reflected in the performance and hour fuel consumption of ploughing set. If the results of measurement No. 7 are taken as a basis, where the effective performance achieved about 1.33 ha/h, then increasing the force in the top link (measurement No. 10) caused an increase in performance of 16.5% along with the reduction in consumption per hectare of 18.1%. Effect of reducing slip among the measurements is also evident from ploughing specific consumption, which is decreased due to higher force in the top link by 14.1%. During the measurement of ploughing set we changed the setting of hydraulic

(a) measurement No. 7



(b) measurement No. 10



(c) measurement No. 11

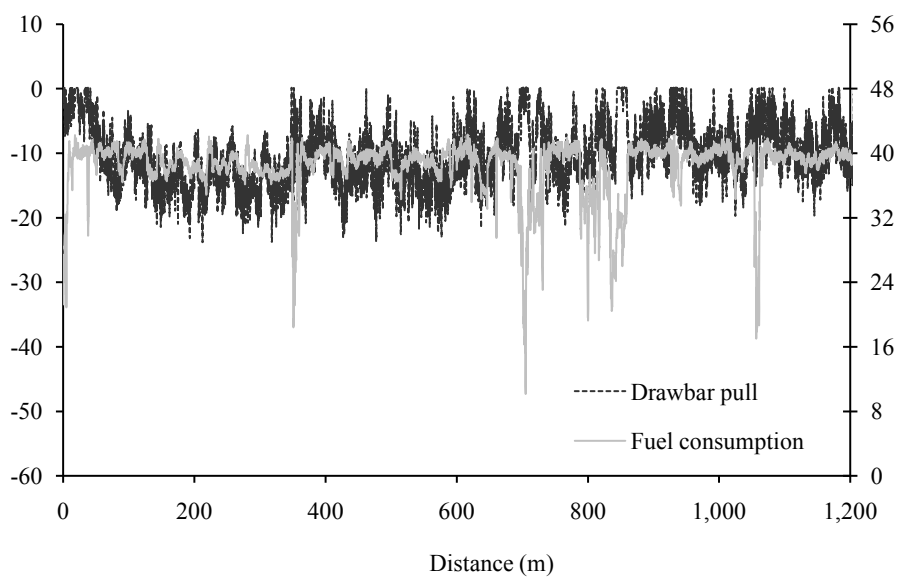


Fig. 8. Course of force in top link and actual fuel consumption

Table 4. Calculated performance indicators

Measurement order	7	8	9	10	11	12	13
Three-point hitch regulation	Pos.	Pos.	Pos.	Pos.	Draft	Pos.	Pos.
Average engine speed n (1/min)	1,979	1,925	1,908	1,863	1,901	1,709	1,732
Average force in top link F (kN)	8.66	10.12	13.88	19.40	18.76	19.53	21.34
Average working width (m)	2.02	1.97	2.06	2.12	2.00	2.10	2.00
Average working depth (cm)	27.20	27.20	27.00	25.90	25.20	25.10	25.60
Variation coefficient – width ν (%)	1.38	0.91	0.99	1.25	1.23	0.45	1.53
Variation coefficient – depth ν (%)	5.34	3.92	5.46	5.79	9.43	8.72	6.33
Operative performance W_{02} (ha/h)	1.16	1.17	1.22	1.35	1.32	1.33	1.34
Operative fuel consumption Q_{W02} (l/ha)	31.10	29.70	28.30	25.40	25.20	23.90	24.20
Ploughing specific fuel consumption Q_{MW02} (ml/m)	11.40	10.90	10.50	9.80	10.00	9.50	9.50
Effective performance W_1 (ha/h)	1.33	1.36	1.43	1.55	1.55	1.55	1.56
Effective fuel consumption Q_{W1} (l/ha)	27.00	25.60	24.00	22.10	21.30	20.50	20.80
Ploughing specific fuel consumption Q_{MW1} (ml/m)	9.90	9.40	8.90	8.50	8.50	8.20	8.20
Average wheel slip (%)	16.59	14.17	14.31	11.21	10.79	11.40	10.90

regulation from positioning to draft with the same length of top link, 765 mm. The results show that the change of hydraulic set-up (positioning vs. draft) did not have a significant impact on monitored parameters and the differences in fuel consumption and performance in hundredths of a percentage. Improving monitored indicators of ploughing set in specific setup of the length of the top link were proved. However, to fully exploit the potential of the set to fuel reduction is not enough; it should be also focused on the internal combustion engine and its mode of operation. Therefore, further measurements were carried out with the aim to keep engine speed between 1,600 to 1,800 1/min at the same length of the top link, 765 mm. Higher gear shifting enabled to reduce engine speed. In this way, a similar performance at higher speeds was achieved, but with lower fuel consumption. If the results of the tenth measurement are taken as a basis, then the engine speed reduction to the level of 1,700 1/min (measurement No. 12) caused a decrease in the effective fuel consumption per hectare of 7.2% (1.6 l/ha) along with ploughing specific fuel consumption savings of 3.5%. Similar issues were also researched by other authors, (e.g. ĎUŽAK, PETRANSKÝ 2002; BAUER, SEDLÁK 2004), who carried out field measurements of ploughing sets, which showed a fuel saving in the area of maximal torque.

CONCLUSION

The results of the realized measurements show a way to improve the fuel efficiency of energy use in ploughing. Transferring the weight of the plough attributable to the depth wheel on the tractor and engine speed reduction by higher gear shifting brings significant fuel savings and increases performance by using the potential of the combination set.

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Received for publication October 3, 2009
Accepted after corrections December 8, 2009

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