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# THE IMPACT OF UPPER LINK LENGTH ON THE OUTPUT PARAMETERS OF A TRACTOR SET

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## Abstract

The aim of the article is to find out the impact of the increase in the force in the upper link of a three-point hitch on the performance parameters of the tractor set Claas Arion and the carried plough Pöttinger equipped with a traction roller and the cultivator Väderstad. During aggregation of the tractor with the plough with an average increase in the force in the upper link of a three-point hitch by 25 kN, a decrease of slippage in average by 8.25 %, a decrease in fuel consumption by 1.875 ml/m$^3$ and an increase in effective performance by 0,225 m$^3$/s were achieved. During aggregation of the same tractor with the carried cultivator with an increase in the force by 40 kN, an average decrease in slippage by 2.64 %, a decrease in effective fuel consumption by 2 l/ha and an increase in effective performance by 0.6 ha/h were achieved. The changes in the observed parameters were demonstrably influenced by the change in the force in the upper link, which was more significantly shown during the aggregation of the tractor with the plough equipped with a traction booster.

Keywords: three-point hitch, work efficiency, fuel consumption, tractor slippage, wheel load

## INTRODUCTION

Soil cultivation and mutual competition of crops, for example, increasing of vegetation density and spatial homogeneity, are the basis for weed control and, in particular, an important protective element in organic farming (Brandsæter *et al.*, 2011). Different methods of intensive soil treatment at different times and at different depths can limit or exclude some chemical interventions focused on the weed control. This brings benefits in the form of increasing organic matter and microbial life in the soil. Further, it can improve water absorption of soil and soil throughput (Gruber and Claupein, 2009).

Agrotechnical operations used in soil treatment are therefore important not only in terms of soil structure and field preparation, but they also have a positive influence on weed control and reduction of the use of herbicides for crop protection in conventional agriculture (Brandsæter *et al.*, 2017).

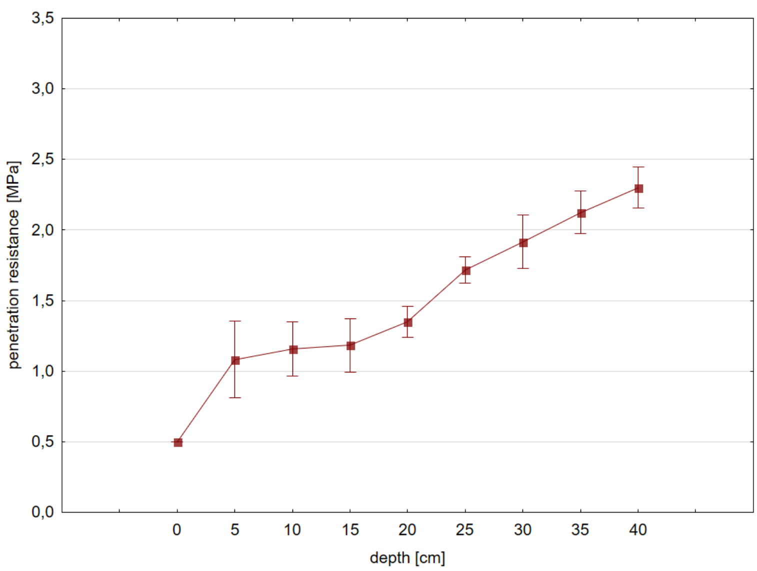
Ploughing as an agrotechnical operation is one of the most basic operations of soil treatment that has been used since the time of ancient Rome and its main task is to incorporate post-harvest plant remains, green manure plants, or organic fertilizer and prepare the soil for sowing (Mustafa *et al.*, 2017). The advantage of ploughing is the elimination of weed and the incorporation of plant residues (Håkansson *et al.*, 1998). Nevertheless, from the perspective of the required tensile power, ploughing belongs to energy-intensive soil treatment operations (Moitzi *et al.*, 2013). During ploughing, there may occur increased slippage, which is an undesirable part of the work of a pulling tractor that moves on an unpaved or slippery surface, such as stubble after harvest or loosened soil after stubble ploughing. During the movement of a pulling tractor on such a surface, there occurs slippage leading to energy dissipation, increased fuel consumption, and reduced performance of the set. Due to the elimination of this phenomenon, tractors are equipped with systems or elements designed to reduce the slippage and maintain the traction capability of the pulling vehicle at the appropriate level in order to achieve the maximum efficiency of the work carried out. The basic equipment of today's tractors includes the control hydraulics of the three-point hitch, which is designed to partially lighten a machine aggregated in the three-point hitch of a tractor in case of increased slippage or force in lower links of the three-point hitch according to pre-set values and thereby transfer a part of the weight of a connected machine to rear wheels of a tractor (Bauer *et al.*, 2013). This will increase the weight on the rear axle of a tractor and reduce the slippage of drive wheels, which will have a positive impact on fuel consumption and the effectiveness of the performance of the given agrotechnical operation (Bauer *et al.*, 2017). The elimination of slippage by loading of the rear axle of a drawing vehicle is also possible with a so-called traction booster used for partially carried or carried machines that are aggregated in the three-point hitch and placed on the aggregated machine. With this device, it is possible to transfer again a part of the weight belonging, for example, to the supporting roller, to the rear wheels of a tractor (Moitzi *et al.*, 2013).

The article deals with the verification of the impact of the correct aggregation of the connected machine and the change of force in the upper link of the three-point hinge on the output parameters of the work sets.

## MATERIALS AND METHODS

The measuring took place on the lands of the agricultural cooperative Jiřice u Miroslavi and it was carried out by the staff of the Institute of Technology and Automobile Transport of Mendel University in Brno. The lands consisted of clay soil and loess as the soil-forming substrate. The measuring was carried out on the stubble field after harvesting of winter wheat. Soil samples were extracted during the tests in order to determine the moisture of the processed soil. After the samples were dried, the weight difference was determined, and it was the basis for the determination of mass moisture. The moisture was 15.16 % on average. Prior to the measuring, the penetrometer resistance of the soil was measured on the given field. The results are shown in Fig. 1.

The tractor Claas Arion 640 Hexashift was used as a drawing vehicle for measuring purposes,




1: *Course of the penetrometer resistance of soil on the stubble field* the selected parameters of which are shown in Tab. I. The tractor was suitably loaded with a set of additional weights at the front of the tractor and in the rear wheels (55 %/45 %).

For practical purposes, the tractor was aggregated with the carried cultivator Väderstad and five-furrow plough Pottinger. The technical parameters of both aggregated machines are shown in Tab. II.

Both machines were connected in the lower links of the three-point hitch that are equipped with tensometric pins for measuring of forces, which are important for the correct operation of the tractor's hydraulic control system. In order to analyse the forces at all three points of the three-point hitch of the tractor that are transferred from the aggregated machine to the drawing vehicle, a tensometric third point was used instead of the standard third point of the three-point hitch, which was equipped with a component for measuring of force. Thanks to this, it was possible to change force in this rod by changing the length

I: *Technical parameters of the used tractor*

| | |
|---|---|
| **Engine** | |
| **Engine capacity [cm³]** | 6788 |
| **Homologation performance value (97/68 EG)[1] [kW/k]** | 128/174 |
| **Gearbox** | |
| **Type** | Hexashift – mechanical gearbox |
| | Gears shifted under load |
| **Tire size** | |
| **Rear axle** | Michelin Multibib 650/65 R38 |
| **Front axle** | Michelin Multibib 540/65 R28 |
| **Dimensions and weights** | |
| **Wheelbase [mm]** | 2860 |
| **Tractor weight [kg]** | 9040 |
| **Weight on the front axle [kg]** | 4895 |
| **Weight on the rear axle [kg]** | 4145 |

II: *Parameters of the used machines (cultivator and plough)*

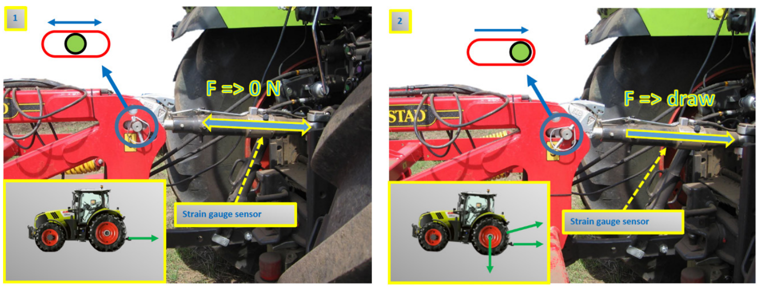
| | |
|---|---|
| **Väderstad Cultus 350** | |
| **Type** | CS 350 |
| **Working scope [m]** | 3,5 |
| **Number of blades** | 12 |
| **Weight [kg]** | 2700 |
| **Power consumption [kW]** | 140–200 |
| **Pöttinger SERVO 45S NP** | |
| **Type** | 9841 |
| **Weight [kg]** | 2580 |
| **Year of manufacture** | 2016 |
| **Number of ploughing bodies** | 4 + 1 |
| **Spacing of bodies [m]** | 0,95 |
| **Frame height [m]** | 0,85 |
| **Frame profile [mm]** | 140 × 140 |
| **Optional equipment** | TRACTION CONTROL |
| | Cylinder for oscillation of the plough while rotating |
| | Memory cylinder SERVO PLUS |

of the upper link of the three-point hitch and thus to transfer a portion of the weight of the aggregated machine to the rear wheels of the tractor. This step affected the performance parameters of the set that were subsequently evaluated.

The first part of measuring was carried out in combination with the carried cultivator and its aim was to evaluate the impact of the change of the force in the upper link of the three-point hinge on the performance parameters of the set. The force in the upper link was changed by length of the upper link. In practice, several measurements took place when the length of the third point connecting the drawing vehicle and the cultivator was changed. The upper link was attached to the oval hole on the cultivator stand. This means that in the first part of the measurement, the third point was loose, and the tractor only pulled the cultivator through the lower links and it was not influenced or lighten or loaded by the cultivator, thus the aggregated cultivator did not significantly affect the tensile properties. The measuring sections were determined on the field and the measuring was always carried out without overlapping, thus with the full scope of the cultivator. The depth of loosening was set to 24 cm, which corresponded to the setting of the chopper roller of the cultivator at position 6.

When working with the cultivator, we took care not to affect the slope of the machine in the longitudinal direction and to preserve the quality of the work performed. This means that there was no excessive relieve of the rear support roller or the inclination of the machine frame, and thus the no different depths of processing of the front row of work sections compared to the rear sections of the machine. From the measured values, the hectare consumption and the effective performance (ha/h) of the set were subsequently calculated. Fuel consumption was taken from the CAN-Bus network and the slippage was calculated on the basis of the measured theoretical speed of the wheels from the on-board network and the actual speed determined by the GPS set placed on the tractor. Individual partial measurements were repeated.

The second part of the practical measurement was carried out in aggregation with the five-furrow plough Pöttinger Servo. The object of this measurement was to find out the impact of the pressure change in the traction roller of the plough, or by increasing the force in the upper link of the three-point hitch on the performance and energy parameters of the set. The pressure was varied in the range of 0 kPa to 150 kPa in the traction roller and each measurement was




2: *Tractor Claas with the tensometer in the upper link of three-point hitch*

3: *Tractor Claas Arion 640 with Väderstad Cultus 350* repeated three times in order to obtain relevant data. The tractor worked with the full fuel supply and the gearbox was set in automatic shifting mode to maintain the tractor's engine in the maximum power range. Measurements were carried out with the adjusted position control of the three-point hitch of the tractor. Fuel consumption, slippage, engine speed, tractor engine load and other parameters were taken from the CAN-Bus network. Further, the depth of the ploughing and the plough scope were measured. All evaluated parameters were calculated for the volume of treated soil.

Regression analysis and t-test for independent samples were used for statistical evaluation. Statistical evaulation were made in the Statistica 12 Cz and regression analysis in QC.Expert 3.3 statistical software.

## RESULTS AND DISCUSSION

### Analysis of measured values in ploughing

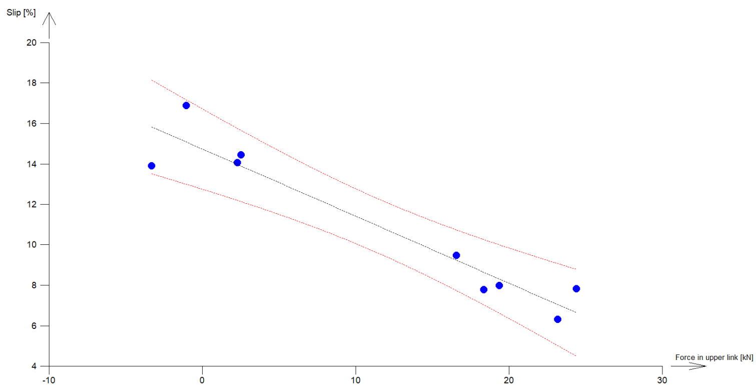
the measuring was made with different pressure in the traction roller. This change of pressure caused change of the force in the upper link. In all variants, the effort was to keep the depth of ploughing depth and the scope of ploughing at the same value. The average ploughing depth was 20 cm and the scope was 2.43 m. The ploughing depth variation was ± 2.5 cm (coefficient of variation 12.5 %) and the scope variation was ± 14.8 cm (coefficient of variation 6.1 %).

First, the dependence between the force in the upper link and the monitored parameter was analysed. The models describing how the force in the upper link is projected to into slippage, fuel consumption and effective performance of the tractor were calculated by the regression analysis. The graphical results of the regression analysis are shown in Fig. 5, 6 and 7 for each parameter.

Furthermore, Tab. III contains calculated regression coefficients and given statistical significance together with the basic statistical characteristics of the regression.

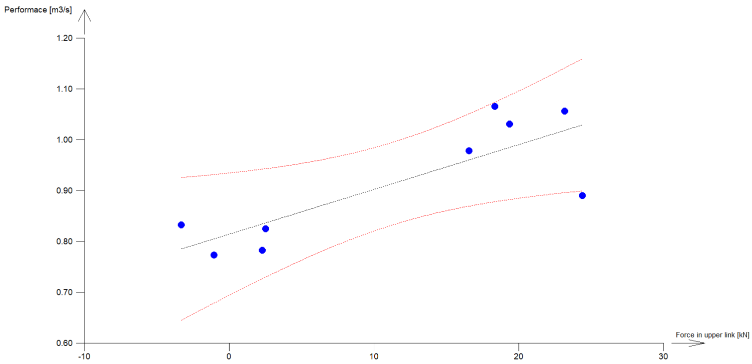
As it can be seen in Fig. 5, 6 and 7 and in Tab. III, linear regression curves–lines – were used for all models. The polynomial transformations showed statistically insignificant regression coefficients (with the significance level 95 %). All three calculated models show a high value of the coefficient of determination (over 82 % of the information contained in the data is explained

4: *Tractor Claas Arion 640 with Pottinger Servo*

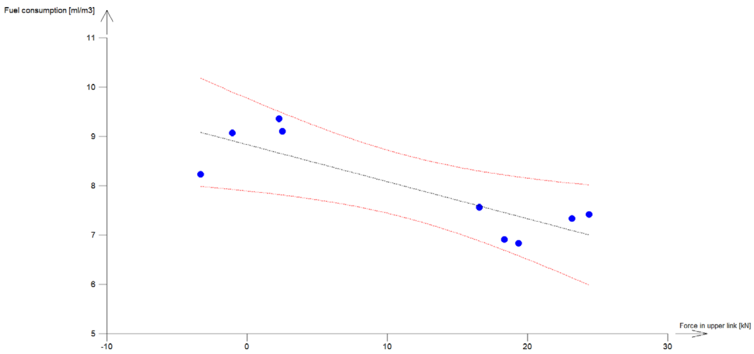



5: *Slippage of the tractor and the force in the upper link with the marked Working-Hotelling confidence bands in aggregation with the plough* by the models) and their regression coefficients are statistically significant.

When analysing the model describing the slippage, it is evident that with increasing force in the upper link the slippage significantly decreases (coefficient of correlation –0.96). When the force in the upper link is increased by 25 kN, the slippage decreases on average by 8.25 %. There is also a negative correlation (coefficient of correlation -0.84) between force and effective consumption. With increasing force in the upper link by 25 kN, there is an average decrease in the effective fuel consumption by 1.875 ml/m³. In case of force and effective performance, there is a positive correlation (coefficient of correlation 0.82). With increasing force in the upper link by




6: *Effective performance of the tractor and the force in the upper link with the marked Working-Hotelling confidence bands in aggregation with the plough*




7: *Effective fuel consumption of the tractor and the force in the upper link with the marked Working-Hotelling confidence bands in aggregation with the plough*

III: *Regression coefficients of calculated models and their basic static regression characteristics*

| Variable | Estimate | Standard deviation | Prob. level | Multiple correlation coefficient R | Coefficient of determination R2 | Predicted correlation coefficient Rp |
|---|---|---|---|---|---|---|
| **Slip [ %]** | | | | | | |
| **Abs** | 14.73 | 0.595 | $p < 0.001$ | –0.96 | 0.91 | 0.69 |
| **Force in upper link** | –0.33 | 0.039 | $p < 0.001$ | | | |
| **Effective fuel consumption [ml/m³]** | | | | | | |
| **Abs** | 8.83 | 0.281 | $p < 0.001$ | –0.84 | 0.71 | 0.23 |
| **Force in upper link** | –0.075 | 0.018 | $p < 0.01$ | | | |
| **Effective performance[m³/s]** | | | | | | |
| **Abs** | 0.81 | 0.036 | $p < 0.001$ | 0.82 | 0.67 | 0.17 |
| **Force in upper link** | 0.009 | 0.002 | $p < 0.01$ | | | |

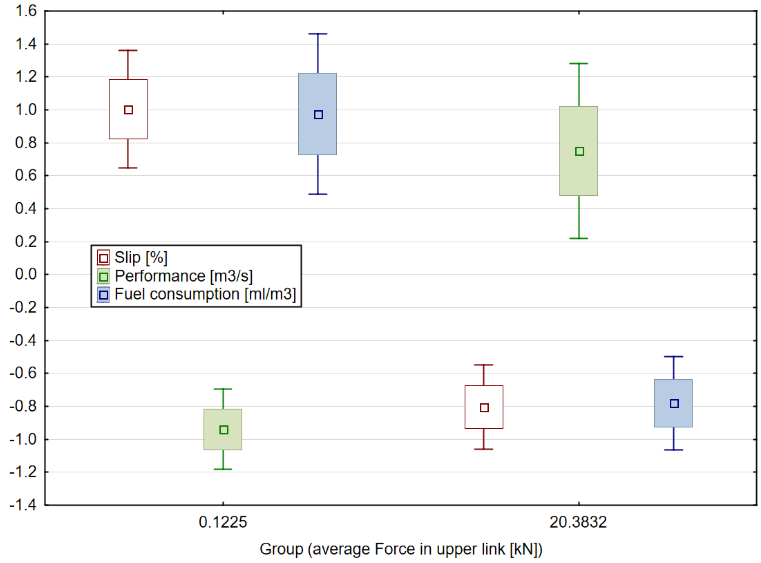
25 kN, there is achieved an average increase in the effective performance by 0.225 $m^3/s$.

A t-test for independent samples was used in order to determine whether there were also statistically significant differences (with the level of significance 95 %) between the group of small forces (on average 122.5 N) in the upper link and the group of great forces (on average 20.3832 kN). For all monitored parameters, a statistically significant difference was found between the groups mentioned above ($p < 0.01$). It is therefore obvious that the force in the upper link has a statistically significant impact on the change of parameters. A box graph was used for graphical representation of the variance (see Fig. 8).

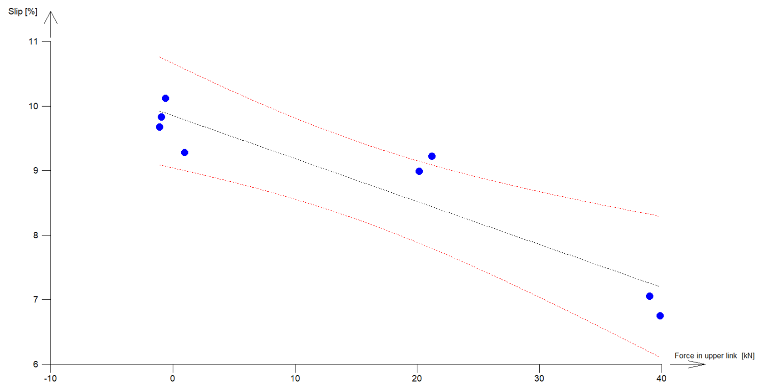
In order to create only one box graph for the monitored parameters, the data used for its creation were standardized. As it can be seen in Fig. 8, the highest fluctuations of values were shown in performance and then in fuel consumption. As mentioned above, a higher force change in the upper link results in statistically significant changes in all monitored parameters. The change of force on average from 0.12 kN to 20.38 kN caused statistically significant changes. With this difference in forces, the average slippage decreased by 6.9 %, effective fuel consumption decreased by 1.73 ml/m3 and the effective performance increased by 0.2 m3/s.

## Analysis of measured values in loosening

the next part of the evaluation included measuring of the aggregation of the tractor with the cultivator. The change in the force in the upper link was realized only by changing its length. Fig. 9, 10 and 11 show graphical results of regression analysis for individual parameters.




8: *The box graph for the tractor in the aggregation with the plough, point: average value, box: average ± standard deviation, whisker: average ± 1,96*standard deviation, standardized data*

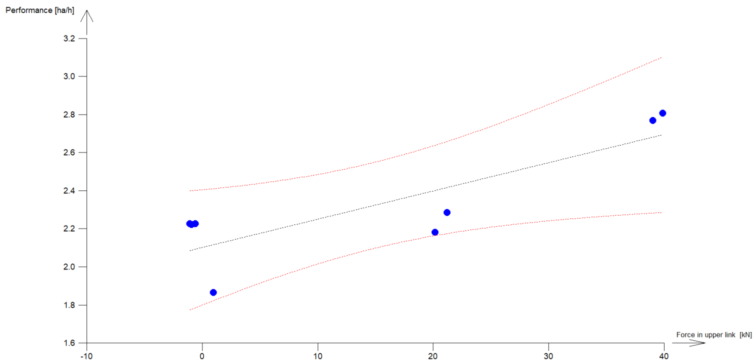



9: *Slippage of the tractor and the force in the upper link with the marked Working-Hotelling confidence bands in aggregation with the cultivator*

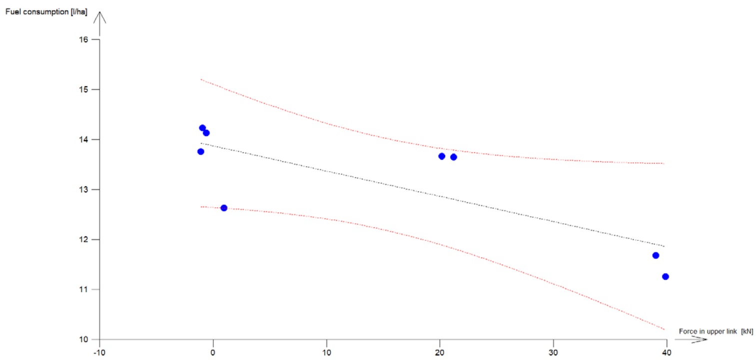
Tab. IV contains calculated regression coefficients and given statistical significance together with the basic statistical characteristics of the regression.

The models describing the dependence of monitored parameters and forces are also created by regression lines. All three calculated models also show a higher coefficient of determination (over 79 %).

When analysing the model describing the slippage, it is evident that with increasing force in the upper link, both the slippage and the fuel consumption decrease. With an increase in the force in the upper link by 40 kN, the slippage decreases on average by 2.64 % and the effective fuel consumption by 2 l/ha. In case of force and effective performance, it is again a positive




10: *Effective performance of the tractor and the force in the upper link with the marked Working-Hotelling confidence bands in aggregation with the cultivator*




11: *Effective fuel consumption of the tractor and the force in the upper link with the marked Working-Hotelling confidence bands in aggregation with the cultivator*

IV: *Tab. V Regression coefficients of calculated models and their basic static regression characteristics*

| Variable | Estimate | Standard deviation | P-value | Multiple correlation coefficient R | Coefficient of determination $R^2$ | Predicted correlation coefficient Rp |
|---|---|---|---|---|---|---|
| **Slip [%]** | | | | | | |
| **Abs** | 9.85 | 0.234 | $p < 0.001$ | -0.93 | 0.87 | 0.61 |
| **Force in upper link** | –0,066 | 0.010 | $p < 0.001$ | | | |
| **Performance [ha/h]** | | | | | | |
| **Abs** | 2.1 | 0.088 | $p < 0.001$ | 0.84 | 0.70 | 0.26 |
| **Force in upper link** | 0.015 | 0.004 | $p < 0.01$ | | | |
| **Fuel consumption [l/ha]** | | | | | | |
| **Abs** | 13.87 | 0.356 | $p < 0.001$ | -0.79 | 0.63 | 0.14 |
| **Force in upper link** | –0.05 | 0.016 | $p < 0.05$ | | | |

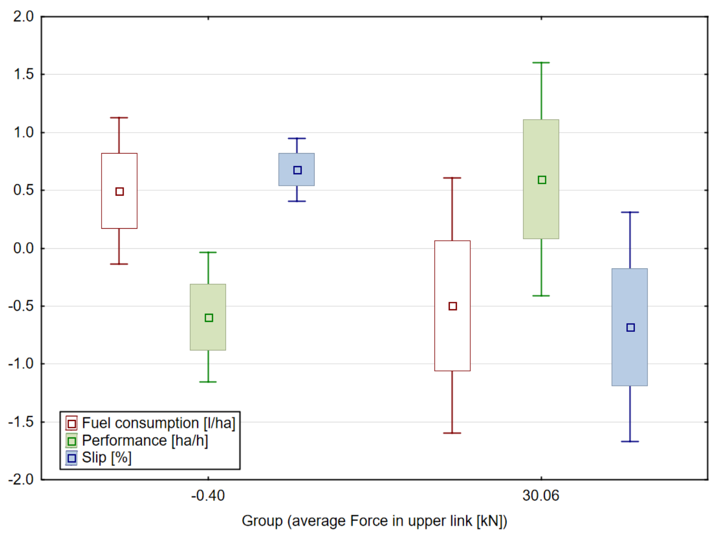
correlation (coefficient of correlation 0.84). With increasing the force in the upper link by 40 kN, the average effective performance increase of 0.6 ha/h.

A t-test for independent samples was used in order to determine whether there were statistically significant differences (with the level of significance 95 %) between the group of small forces (on average -400 N) in the upper link and the group of great forces (on average 30,06 kN). Only in case of the slippage there was found a statistically significant difference ($p<0.05$) between the above-mentioned groups. Thus, it is evident that force in the upper link has no statistically significant impact on performance and fuel consumption. A box graph was used for graphical representation of the variance (see Fig. 12).

As it can be seen in Fig. 12, the highest fluctuations of values were shown in the measuring with higher force in the upper link. As mentioned above, a higher force change in the upper link results in a statistically significant change only in the slippage. The average change in force from -0.40 kN (pressure) to 20.38 kN (pull) caused an average decrease of slippage by 1.7 %, the effective fuel consumption by 1.13 l/ha and an increase in effective performance by 0.38 ha/h.

As the results show, we can talk about the positive effect of the tensile force in the upper link on the performance parameters of the set, especially in case of the plough. With increasing force in the upper link, there is a statistically significant decrease in slippage, effective fuel consumption and an increase in performance of the plough, in case of the cultivator only a statistically significant decrease in slippage.

The paper from Bauer *et al.* (2017) deals with a similar issue and it clearly demonstrates a significant impact of the adjustment of the upper link and the associated transmission of forces on the rear wheels of the pulling vehicle as a tool for increasing the effectiveness of performed work while maintaining the qualitative parameters. Similar results in the verification of the impact of the correct length of the upper link of the three-point hitch during ploughing were reached also by Čupera and Šmerda, where a decrease in slippage and consequently the overall improvement of performance parameters of the set is demonstrably visible. Thanks to a reduction in slippage, work speed increased and fuel consumption decreased by 1.6 l.ha-1. (Čupera and Šmerda 2010). A so-called traction roller can be additionally used to increase the transfer of load on the rear wheels of the pulling vehicle. This would result in increasing the load transferred from the aggregated machine and thus increasing the weight transmission and improving traction properties of the tractor (Moitzi *et al.*, 2013). In case of measuring the tractor John Deere 8295 with the plough Pottinger Servo 6.50 from 2014, there were reached 12 % decreased of fuel consumption with the maximum pressure in the traction roller. Similar results were achieved with the tractor set Claas Axion 850 and the plough Pottinger 6.50 Plus NOVA, which achieved average 13.2 % decreased of fuel consumption. At the same time, the effective performance of tractor was increased 14.5 %.




12: *The box graph for the tractor in the aggregation with the cultivator, point: average value, box: average ± standard deviation, whisker: average ± 1,96*standard deviation, standardized data*

## CONCLUSION

The achieved results of measuring of the tractor Claas Arion with the plough Pöttinger clearly show the positive impact of the use of the traction device, a so-called "traction booster" on the output parameters of the ploughing set. It is clear from the regression analysis results that the increase of the force in the upper link of the three-point hitch by 25 kN causes a decrease of slippage on average by 8.25 %, a decrease of the fuel consumption by 1.875 ml/m3 and an increase of the effective performance by 0.225 m3/s.

In the second part, the tractor set Claas Arion with the cultivator Vaderstad was evaluated, where the targeted loading of the rear axle of the tractor was only carried out by changing the length of the upper link of the three-point hitch. In this case, increasing of force by 40 kN caused an average decrease of the slippage by 2.64 %, a decrease of the effective hectare fuel consumption of 2 l/ha and an increase of the hectare performance by 0.6 ha/h.

The measured results show a positive impact of the force in the upper link of the three-point hitch, which was more significant in case of the tractor set with the plough equipped with an additional device for increasing of traction. In the case of the agrotechnical operation - ploughing, the performance and energy parameters are stated in m3 of processed soil in order to assure higher objectivity. Comparable results can be found in the case of measurements that dealt with a similar issue but under different conditions or with different machines. In such cases, the fuel consumption saving with correctly adjusted machines or with the use of traction cylinders reaches several litres and there is also a significant positive effect in terms of slippage and performance of work sets.

Acknowledgements

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