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INVESTIGATION OF THE EFFECT OF A SUSPENDED WORKING MACHINE ON TRACTION FORCE

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Abstract

It is always an aim in agricultural machine operation to understand the tractor-machine-soil relationship precisely. The working machine is often connected to the tractor with a three-point linkage system. The three-point linkage system coordinates the movement of the tractor-work machine group, increases the traction force, and also enables the adjustment of the coupled work machine. Understanding how it works is very important. In this paper, we examine the effect of the connection points of the three-point linkage system on the change in the adhesion weight force in a specific case, in the case of U532DT tractor and PP2-30 suspended plough.

Keywords: *three-point linkage system, adhesion force, traction force, suspended plough.*

1. Introduction

1.1. Traction force of an agricultural power machine

The tractor is the energy source of agriculture, its task is to tow and operate the working machine. A good use of the traction power of a tractor contributes to the reduction of agricultural environmental impact **[1]**, **[2]**. The traction force is the adhesion force appearing on the driven wheels of the power machine. Its maximum value depends on the quality of the surfaces between the soil and the driven wheels and the wheel load:

$$F_{vmax} = \mu \cdot G_{adh} \text{ [N]}, \quad (1)$$

where: μ adhesion coefficient; G_{adh} adhesion weight force [N].

The adhesive weight force is the weight force exerted on the driven wheels of the tractor. Generally, 2/3 of the tractor's weight is considered adhesive weight force **[3]**, but in the case of four-wheel drive, the entire tractor's weight is adhesive weight force.

The maximum traction force can be increased by increasing the adhesion coefficient and the adhesion weight force. There are several options for increasing the adhesion weight force. In this paper, we examine the additional weighting effect of the work machine suspended on the power machine.

In the paper, we study and measure the load of the weight of the suspended work machine on the driven wheel. This increases the adhesive weight force, thus causing an increase in traction force when towing. The work machine is attached to the power machine with the three-point linkage system.

1.2. Methods of determining traction force

Traction force is measured directly with measuring equipment or determined indirectly **[4]**.

1.2.1. Direct measuring methods

In this case, the forces occurring at different points of the tool are measured during work and the traction force is determined from that. This can happen:

– by measurement in laboratory conditions;
– by measuring in field conditions.

Laboratory measurements take place in a soil bin. The main parts of the soil bin: soil modelling soil tank, with rails on both sides; tillage tool holder that moves on rails; power source and propulsion system that models the tractor; measurement/data collection and analysis system. The soil bin is large, takes up a lot of space and has a high investment cost.

A force measuring frame is used for outdoor measurements. The force measuring frame is placed between the mounted implement and the tractor's three-point hitch. Force-measuring sensors are attached to the force-measuring frame, which measure the traction force/traction resistance in the horizontal plane and the lifting/loading forces in the vertical plane. The size of the force measuring frame is large and robust. In general, each research centre and factory prepare its own force measuring frame. Not commercially available.

1.2.2. Indirect determination method

In this case, measurements are made in experimental conditions, and from these values the actual traction force during work is deduced.

A working machine connected with a three-point linkage system causes an increase in traction force by increasing the adhesive weight force [4]. Thus, the forces measured on the suspended working machine can be suitable for indirectly determining the change in traction force. With dynamic modelling, the forces acting on the group of machines, which are essential in terms of the phenomenon, can be revealed. The forces can be analysed and the factors influencing the traction force can be selected based on this [5].

2. The investigation

2.1. Theoretical background of the investigation

Part of the weight of the suspended working machine is loaded on the power machine, thus influencing the G_{adh} adhesive weight force, and indirectly the traction force. We examine the effect of the additional weight of a suspended working machine.

The measurements were carried out on the U523DT universal horticultural tractor and PP2-30 suspended, two-plough-body plough machine group. This test can also be performed when the machine group is stationary.

With dynamic modelling, we reveal the forces acting on the group of machines, which are essential from the point of view of the phenomenon.

In the vertical plane the forces on the tractor-suspended plough machine group are in balance [6]:

$$R_E + R_H - G_T - G_E + R_K = 0 \text{ [N]} \quad (2),$$

where:

– R_E and R_H are soil resistance forces under the wheels of the power machine [N];
– G_T is the weight force of the tractor [N];
– G_E is the weight force of the plough [N];
– R_K is the soil resistance force under the depth limiting wheel [N].

Plowing requires a large tractive force, for this reason the 4×4-es drive is mostly used on the power machine, so the G_{adh} can be calculated with the relationship (2):

$$G_{adh} = R_E + R_H = G_T + G_E - R_K \text{ [N]}. \quad (3)$$

The relation (3) indicates that the R_K force affects the value of G_{adh}.

Therefore, the soil resistance force under the depth- limiting wheel of the suspended working machine is suitable for characterizing the change in traction force.

To examine and analyse the R_K force, we write down the moment balance of the forces acting on the plough at the vertical instantaneous centre of rotation P [5]:

$$-R_K \cdot (x + l_K + l) + G_E \cdot (x + l + l_G) = 0, \quad (4)$$

where: x is the distance of the vertical instantaneous center of rotation from the wheel center [m]; the distances l_K, l, l_G can be seen in Figure 1 [m].

The R_K soil resistance force can be calculated with the relation (4):

$$R_K = \frac{G_E \cdot (x + l + l_G)}{(x + l_K + l)} \text{ [N]}. \quad (5)$$

The relationship (5) indicates that the magnitude of the R_K is influenced by the distance x. The magnitude of the distance x is influenced by the connection point of the three-point linkage system (Figure 1).

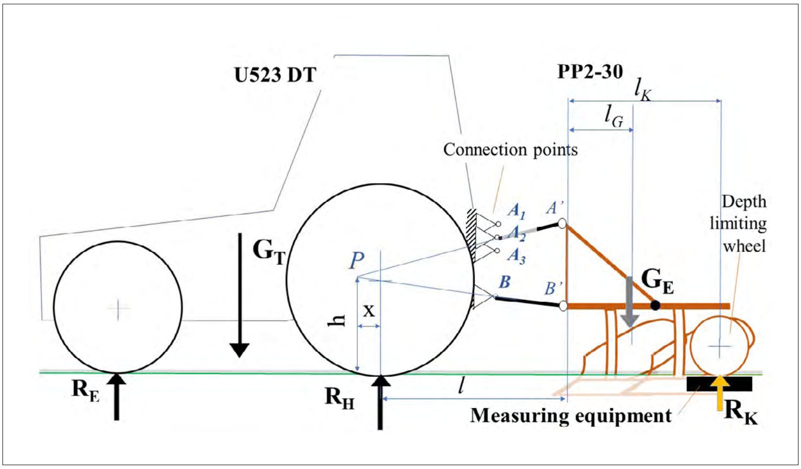

Fig. 1. *Dynamic model of a tractor-suspended working machine.*

2.2. The method of investigation

It is assumed that the connection points of the upper support rod of the three-point linkage system have an effect on the adhesion weight force G_{adh}.

We measure the soil resistance under the depth-limiting wheel in three cases, at the three connection points of the upper support rod: in points: A_1, A_2, A_3 (Figure 1).

2.3. The measuring equipment

The measuring equipment is actually a scale that is placed under the depth limiter wheel. Its structure can be seen in Figure 2:

- mechanical part: holder cassette, cover;
- electronic part: control-data collector, indicator, printed wiring board, buttons;
- force measuring sensor.

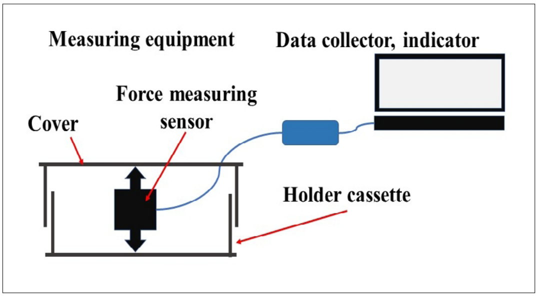

Fig. 2. *Construction principle of the measuring equipment.*

2.4. The measurements

The measurements were carried out in June 2022 in The Faculty of Technical and Human Scientist Târgu-Mureș Medicinal Plant Garden of Sapientia Hungarian University of Transylvania.

We assembled the tractor-plough machine group and we adjusted the plough: the longitudinal horizontality with the screw spindle of the upper support arm; the transverse horizontality with the lift links; the working depth with the depth-limiting wheel to 21 cm.

The state of the tractor-plow machine group during operation can be seen in Figure 3. The tractor's right wheel is at the bottom of the previously plowed furrow; thus, the tractor's axis is not horizontal, we paid attention to this when creating the measurement conditions.

Fig. 3. *The measuring location.*

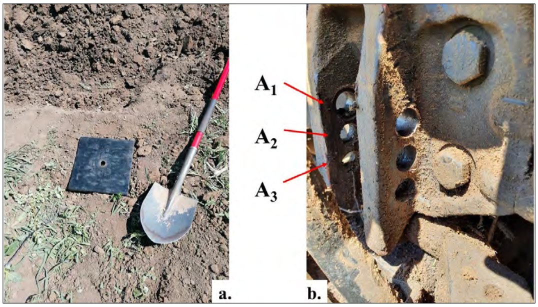

Fig. 4. *The measurement conditions: a) Buried measuring equipment; b) Connection points.*

Table 1. *Averages of measurement data*

	Measurement I.			Measurement II.		
Connection points	A_1	A_2	A_3	A_1	A_2	A_3
R_K average [N]	1002.93	978.27	1028.23	904.87	849.33	952.53
s, deviation	0.12	0.48	9.11	2.79	1.38	3.69

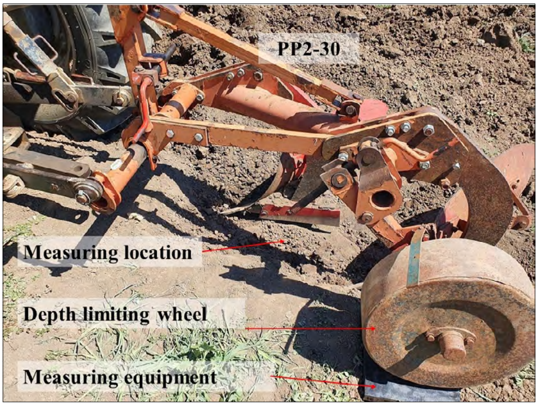

Fig. 5. *Measurement at the measuring location*

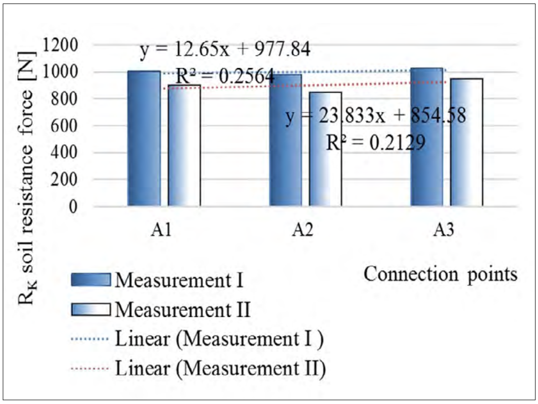

Fig. 6. *Soil resistance force under the depth-limiting wheel of the suspended PP2-30.*

We dug the measuring location of the plough bodies at 21 cm depth.

We determined the location of the depth-limiting wheel with trial pulls, and there we dug in the measuring equipment up to the soil surface (**Figure 4.a.**).

We calibrated the measuring device with a known mass.

We fixed the upper support arm of the three-point linkage system at point A1 (**Figure 4.b.**) and we performed the measurement, then we proceeded similarly for the connection point A3.

We repeated the series of measurements (**Figure 5**).

2.5. Processing of measurement data

The averages of measurement data are described in **Table 1**.

The data were displayed (**Figure 6**).

A moderate correlation between the connection points of upper rod and the soil resistance under the depth-limiting wheel can be shown, $R_I = 0.5$, $R_{II} = 0.48$ [7].

The soil resistance under the depth-limiting wheel is the highest in the lower connection point A_3, for both measurements. The high soil resistance means that the plow rests on the soil, so the weight on the driven axle of the power machine is less, i.e. the additional weighting effect of the suspended PP2-30 machine is smaller.

We verified with a hypothesis test that the connection points have an effect on the ground resistance under the depth-limiting wheel at the $p = 0.1$ level. [7]

The values of G_{adh} calculated with relation (3) in the versions with and without suspended work machine are summarized in **Table 2** and shown in **Figure 7.**

The machine data used in the context: tractor weight force $G_T = 27566.1$ N, plough weight force $G_{eke} = 2452.5$ N.

The suspended working machine increases the value of G_{adh} so it has effect of increasing traction force. The additional weighting effect was checked with a hypothesis test, the difference is very significant at the $p = 0.1$ level [7].

Table 2. *Traction increasing effect of suspended PP2-30 work machine*

Connection points	A_1	A_2	A_3
R_K average [N]	953.90	913.80	990.38
G_{adh} with suspended work machine	29064.70	29104.80	29028.22
G_{adh} without suspended work machine	27566.10	27566.10	27566.10
Traction force increase %	**5.44**	**5.58**	**5.30**

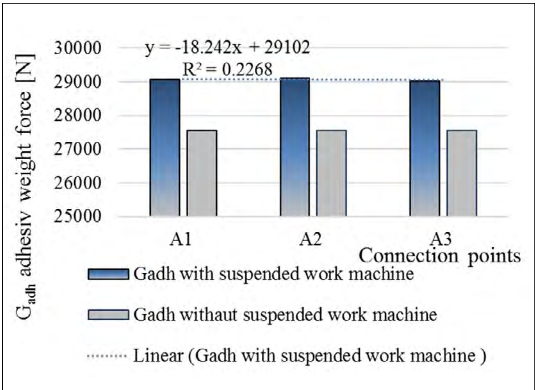

Fig. 7. *Changes in adhesion weight force due the suspended work machine and the connection points/*

3. Conclusions

We verified by measurement that the suspended working machine increases the adhesion weight force, thus indirectly affecting the traction force.

We proved that the connection points of the three-point linkage system influence the magnitude of the adhesion weight force. The lower attachment point causes the smallest additional weighting effect, that is here the effect on the traction force is the smallest.

The trend of the measurement data confirms the highest additional weighting effect can be expected at the upper connection point. The results of the measurement were influenced by the conditions of the measurement: the preparation of the measuring location, the placement of the plow on the measuring equipment, the effect of the connection points on the horizontality of the machine. This explains the measurement data large deviation and the discrepancy from the expected values in the middle connection point.

Based on our measurements, the PP2-30 mounted implement results in an average increase in traction force of 5.44 %.

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