INFLUENCE OF ADJUSTABLE FRONT BALLAST ON TRACTOR FUEL CONSUMPTION AT WINTER WHEAT STUBBLE HARROWING

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Abstract. Ordinarily a tractor works under variable draft, what brings unavoidably mass transfer of the tractor, which negatively affects the front and rear wheel cohesion with soil and pull. This situation causes discrepancy when loaded MFWD (mechanical front wheel drive) tractor under draft in four-wheel drive regime mode, and this leads to the increase of the front wheel slip. The gross traction ratio developed by the dynamic weight on the powered wheel is different than it should be. The cohesion of the front wheels is changed from maximum, when the draft is minimal, to minimum, when the draft is the highest. The cohesion of the rear wheels is changed contrarily. Mass transfer changes the load of the tractor axles, with the implement draft towards mass position to the rear wheel, the slip of the front wheels becomes unstable. For solving such impact of mass transfer a special attachment of the front ballast with a possibility to change its forward distance was made. The aim of the research was to establish how much the adjustable front ballast can adjust the slip of the tractor, maintain a constant reaction on axles and reduce the fuel consumption. The investigative tractor "Ford 8340" and a compact disc harrow were used in this research. Mathematical method was applied for the search potential of ballast that can generate an appropriate weight transfer of the front and rear axis load. A field test for evaluating of the front ballast adjustable position to wheel slip and fuel consumption was performed. The correlation of the adjustable front ballast, the tractor axle load balance and wheel slip during the disc harrowing operation was developed. The results show that the adjustable front ballast can compensate the draft load on the front and rear axis and improve the wheel-pull distribution by 11% and to reduce the fuel consumption by 5% in the field conditions compared to the case when the front ballast was used by default.

Keywords: adjustable ballast, shallow tillage, working speed, fuel consumption.

Introduction

To match the rising requirements of environment protection, the soil tillage intensity is reduced; mostly, it is achieved by reducing the tillage depth to shallow harrowing. As the tillage depth decreases, the working speed can be increased to high-speed operation regime. According to exploration of literature, it is determined that at increased working speed the mass of tractor must be decreased with the purpose to lower fuel consumption [1-3]. From formula of the additional fuel consumption calculation for transportation of the ballast weight, $FC_{Mb} = M_B \cdot g \cdot f \cdot v \cdot FC_{sp}$, the mass and speed are the main variable factors (M_b – mass of ballast, g – acceleration of free fall (9.81 m·s^{-2}), f – coefficient of rolling resistance, v – working speed, FC_{sp} – specific fuel consumption of the tractor) [4].

Appropriate ballasting of driving wheels solves some problems, for example, prevents from tractor slipping [5]. According to the authors, the draft performance is reliant on the ballast mass [6 – 8]. The size of the ballast can regulate the mismatch of the linear speed ratio of the axle wheels what the tire deformations and the draft load of the puled implement cause [9]. On the other hand, it is important that high load increases tire deformation, i.e., their rolling resistance, with drawbar pull on soil and for transportation on road it is necessary to carefully consider ballasting of the tractor [10, 11]. Front ballast prevents overturning of the tractor backwards and prevents from mass transfer, as known, the tractor works under a drawbar load, hence the implement draft [12]. The load of the draft changes the grip force of the front and rear axle, as the uneven front and rear wheel slippage can appear [13]. Therefore, the vertical weight force of the front driving wheels for grip is used only partially. Appropriate front ballast may adjust the front and rear wheel grip ratios and assure correct drawbar [14, 15]. The obtained results from Shafaei S.M. et al. [16] indicated that the slip efficiency nonlinearly dropped from 0.94 to 0.74 as simultaneous augmentation of the slip ratio of the rear wheels to that of the front wheels (0.72 – 0.87) along with ratio increment of gross traction force of the rear wheels to that of the front wheels (1.81 – 4.93). This situation arises, when the draft force of the implement increases from 8.58 to 25.85 kN. Hence, it can be pointed out that the maximum slip efficiency, as well as the overall power efficiency of the MFWD tractor in tillage practices would be achieved at the same slip in accordance with the same gross traction force of the front and rear wheels [16].

To prevent the weight transfer, the ballast weight should be changed, if the working conditions are changed. Variable water ballast was investigated by Clark and Van de Linde, developing a system which could fill or empty 140 L ballast tanks over each wheel of 180 kW tractor [17]. Self et al. equipped a 130 kW four-wheel-drive tractor with a rear-mounted ballast rack so that the proportion of the total static weight on the front axle could be changed in the range from 35 to 47% [18].

The second cause to make tractors lighter is to reduce soil compaction, because tillage becomes less intensive and the risk of soil degradation increases. Tractors can be lightened by dismounting the mass, in this research case, by reducing the front ballast. In some situations, ballasting is unavoidable, but it is purposeful to connect two tasks of the environment protection (fuel and soil) and make the tractor lighter. A special ballast positioning system was made. This research investigates the results of adjusting the front ballast position for the grip of the front and rear tires at hight speed winter wheat stubble cultivation.

Materials and methods

The investigative tractor "Ford 8340" was instrumented with the data acquisition system and used to measure the draft, fuel consumption and the velocity speed. Full mounted compact disc harrow "KBT-4" 4 m width, was used in the field test. The special ballast positioning system was made (Fig. 1).

Fig. 1. **Front ballast by default (a) and front ballast with a possibility to change its forward distance (b)**

According to the tire load data sheet chart, the front and rear tyre inflation pressure value was 23 psi (1.6 atm·cm^{-2}) for winter wheat stubble field conditions. The static weight distribution was 45% front and 55% rear axles, at zero front ballast, for a total static weight 49.3 kN.

Table 1

Specification of tractor and compact disc harrow

Parameter	Value
Mass of the tractor "Ford 8340"	5030 kg
Front tires	"Petlas" 440/65 R24
Rear tires	"Alliance" 18.6 R38
Wheelbase	2.6 m
Mass of the disc harrow "KBT-4"	1750 kg
Disc diameter	510 mm
Consist	one row of 10 mm tines and spring ring roller

The measurements were made of the weight of the tractor axles when acting the draft force and the fuel consumption estimation at the stubble harrowing test.

Weight of tractor axles were measured by the scales "Portable Axe Weigher WPD-2" at three replications of the ballast variation. The axle weight data deviation of measurements did not overrun 1%. The tractor was loaded with numerous draft forces with the hydraulic cylinder (Fig. 2). The draft induces weight fluctuation on the front and rear wheels of the tractor and its axles were weighted. This determines the dependence of the front and rear wheel load changes with the draft acting. By the simulation of the draft force uncertain mass centre point of the tractor was estimated.

Fig. 2. **Measuring of axis weight when draft force was simulated by the hydraulic cylinder**

The distance of the tractor mass centre from the rear axis:

$$L_W = \frac{m_f \cdot L}{W_T}, \quad (1)$$

where W_T – tractor mass,
m_f – mass of the front axis,
L – base of the tractor.

Total distribution of the mass centre transfer, when acting draft force:

$$\Delta L_W = \frac{m_{f\max} \cdot L}{W_{T\min}} - \frac{m_{f\min} \cdot L}{W_{T\max}}, \quad (2)$$

where $m_{f\max}$ – mass of the front axis at maximum draft force,
$m_{f\min}$ – mass of the front axis at maximum draft force minimum load on the front axis,
$W_{T\min}$ – tractor mass without draft,
$W_{T\max}$ – tractor mass with full draft force.

The minimal ballast mass $M_{B\min}$ was calculated from torques of the weight forces acting around the rear wheel (Fig 3). In a requirement for safety steering with mounted machines, the minimum ballast mass ($M_{B\min}$) on the front axle must be more than 20% of the overall mass of the tractor.

$$M_{B\min} = \frac{W_{im} \cdot L_2 - 0.2 \cdot W_T \cdot L_W}{(L_1 + L)} \quad (3)$$

where W_{im} – mass of the implement draft;
L_1 – distance of the front ballast mass;
L_2 – distance of the implement mass to the rear axis;
L_W – distance of the mass centre of the tractor from the rear axis.

Draft force of the implement changes the reaction forces of the front and rear axles as the uneven front and rear wheel drawbar with the vertical load of the front driving wheels for grip is used only partially. The overall traction drawbar force at constant speed with implement is obtained:

$$F = F_f + F_r = \varphi \cdot R_f + \varphi \cdot R_r \quad (4)$$

where F_f and F_f – traction force of the front and rear wheels;
R_f and R_r – vertical reaction forces of the front and rear wheels;
φ – coefficient of grip utilization (on stubble 0.65).

Vertical reaction forces of the front and rear wheels R_f and R_r, when acting draft force:

$$R_r = \frac{W_T \cdot (L - L_W) - M_B \cdot L_1 + M_f + F_D \cdot H_D}{L} \quad (5)$$

$$R_f = \frac{W_T \cdot L_W + M_B \cdot (L + L_1) - M_f - F_D \cdot H_D}{L} \quad (6)$$

where L_W – distance of the mass centre from the rear axis;
F_D – drawbar force;
H_D – height of the drawbar;
M_B – mass of the ballast.

The performance on the working speed and ballast position mode data were collected from field stubble harrowing by three replications. The measurements of the fuel consumption (L·h^{-1}) were done by an added fuel consumption gauge, fuel cooler, fuel filter and the air separator in the main fuel system of the engine; working speed of the tractor – by an original speed radar of the tractor connected to the data recorder "SKRT". Fuel consumption per hectare was found:

$$FC_{ha} = \frac{FC_h}{3.6 \cdot \tau \cdot v}, \text{ L·ha}^{-1} \quad (7)$$

where FC_h – hourly fuel consumption, L·h^{-1};
τ – utilization ratio of the working time,
v – working speed, m·s^{-1}.

Fuel consumption for the turns of the unit was not included. Deviation of data was based on the characteristic of the devices. Grip of tires becomes inappropriate, because the driving force of the front and rear wheels also becomes unstable, since the weight transfer changes the load on the tractor axle wheels. The slip of a tractor is described as the ratio between the decreased actual speed v and the theoretical speed v_ω. Slippage is estimated by expression [5]:

$$\delta = \frac{v_\omega - v}{v_\omega} = \frac{r_d \cdot \omega - v}{r_d \cdot \omega} \quad (8)$$

where: r_d – dynamic radius of the wheel, ω – rotation speed, v – actual speed.

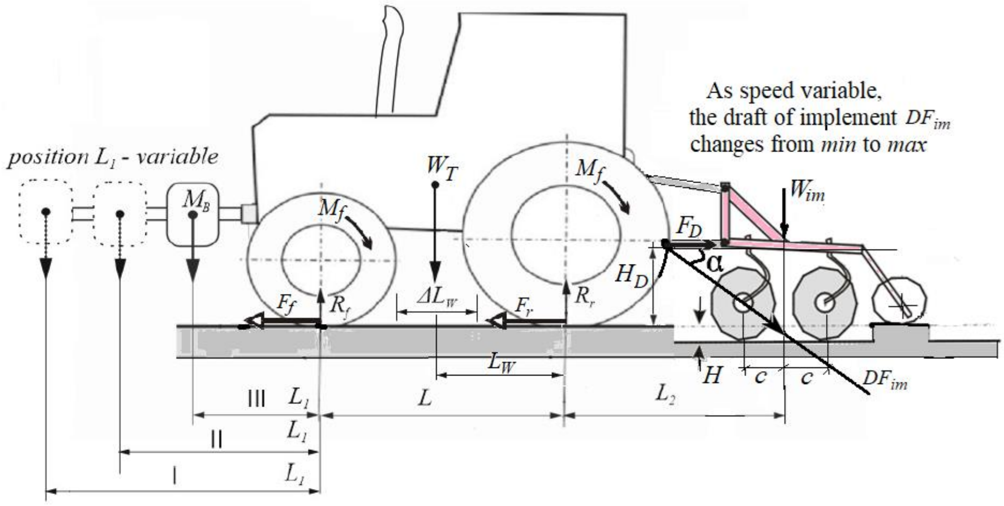


Fig. 3. **Scheme of aggregate and acting forces, L_2 = 1.8 m, M_B = 120 kg**

Results and discussion

When the tractor works relating to variations of the traction force, the distribution of the vertical load on the front and rear axles also varies, and it is difficult to set. The scientist Frank Zoz calculates the weight transfer from the front to the rear wheels due to the traction force agreeing to the simplified equation [8]:

$$\Delta W = \xi \cdot F_D \quad (9)$$

where ξ = 0.65 – for mounted implement with automatic depth/force position control;
ξ = 0.45 – with semi mounted machines;

ξ = 0.20 – for trailing machines.

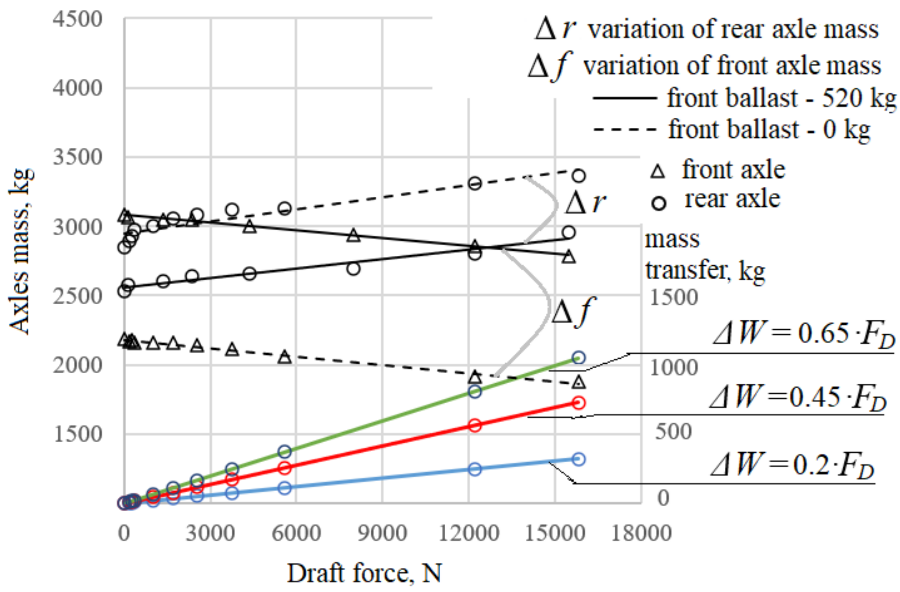
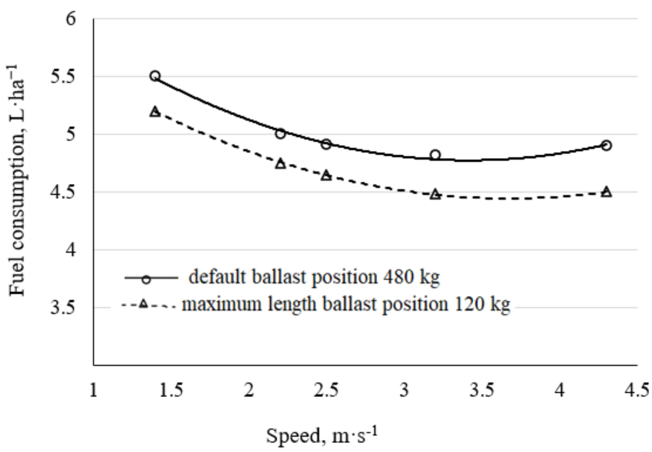


Fig. 4. **Variation of front and rear axle weight according to draft force**

Increasing of the ballast mass from 0 to 520 kg, the load on the front axle increases more than the traction force increases the load of the rear axle (Figure 4). Changing of the ballast mass from 0 to 520 kg, the weight of the front axis varied from 2070 to 2960 kg, the weight of the rear axis varied from 2540 to 3010 kg. It means that the addition of the front ballast changes the mass of the front axle significantly, including the overall mass transfer of the tractor. The curves tilt of mass transfer calculation according to F. Zoz, most similar with the coefficient ξ = 0.2. It means the weight transfer around 250 kg. With ballast of 120 kg at the longest position of the ballast positioning system at draft, the same weight of the front axis was achieved as without draft in the static state.

Sadek M. A. et al. estimated that the tillage speed strongly influenced the draft force, the draft force ranged from 928 N to 1644 N for the speeds of 12 km·h^{-1} to 20 km·h^{-1} [19]. It means with increasing the field speed, the draft force increased too, and as the field speed is variable, the weight transfer towards changeable position and load on axles requires annoying the front ballast mass. As the draft force increases, when the field speed is growing, and to avoid the front tire grip imbalance and slip increase, the front ballast should be added.

The impact of the forward distance of the ballast mass to the tractor weight transfer at various working speed was predicted and examined on stubble field conditions. The ballast positioning system must keep the identical weight distribution on axis at stubble harrowing and not increase slip.



Slippage coefficient δ, (speed 4.3 m·s^{-1})

L 1	L 2	L 3	480 kg
8.7	9.2	9.8	9
8.8	9.8	10.2	9.5
9.2	9.5	10	8.5
8.9	**9.5**	**10**	**9**

note: L1, L2, L3 –position of ballast 120 kg.
numbers in red – more than average
circled number – more than 10%

Fig. 5. **Variation of fuel consumption and slippage coefficient at differ ballast positions**

The efficiency of fuel use is better reflected in fuel consumption per hectare of tractor field works, in this case – for stubble tillage. The results in Fig. 5 illustrate that it is possible to perform stubble tillage with fuel consumption from 4.4 to 5.5 L·ha^{-1}, depending on the selected speed mode and front ballast position. The dependencies of fuel consumption on two parameters were found: the ballast weight and position by using the same working adjustment of the disc harrow. The fuel consumption per hectare increases by increasing of the ballast mass, but decreases with increasing of the working speed to optimal load of the engine, which is appropriate at 80% of full power.

The research determined that the front ballast positioning can slightly adjust the slippage of the tractor at a higher speed and reduce the fuel consumption. The front ballast positioning system can slightly adjust the load distribution on the front and rear axis, to keep slippage of the tractor at the same values as the ballast mass was at the default position.

Conclusions

1. Based on the results, when the draft force varied from 0 to 15 kN, the front axis weight changes from 2070 to 1880 kg and the rear axis load changed from 3010 to 3360 kg without front ballast.
2. The ballast positioning system was effective in maintaining the level of the slip under load conditions. By adjusting the forward distance of the front ballast 120 kg, the compensation of mass transfer was achieved. When the ballast was maximum 480 kg or full-length distance with 120 kg mass, the same slippage was achieved only 8.9-9.0% in both cases.
3. From the data obtained here it might be expected that the ballast positioning system could result in improvements at field works. The fuel consumption level, by using the ballast positioning system, in this research was considered for stubble harrowing, was improved by 5% compared to the case when the front ballast was used by default.

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