The effect of the tractor engine rated power on diesel fuel consumption during material transport

L. Jílek[1], R. Pražan[1], V. Podpěra[2], I. Gerndtová[3]

[1]*Faculty of Engineering, Czech University of Life Sciences in Prague, Prague, Czech Republic*
[2]*Anser, s.r.o., Prague, Czech Republic*
[3]*Research Institute of Agricultural Engineering, Prague-Ruzyně, Czech Republic*

Abstract: The authors of this paper determined in a field measurement how the change of the tractor engine power in a tractor-trailer combination affects the diesel fuel consumption related to the unit of transport output (l/tkm) and the transport performance (t/h) in the conditions of a mountainous region. Transport combinations (tractor – trailer) were compared that were formed by a tipping trailer connected to three tractors with different engine powers when passing allong a route with the gradient of 0°–5.5°. It is obvious from the results of these measurements that the diesel fuel consumption differed by up to 27% in individual combinations. The lowest specific consumption on the measured route was found in the combination with the tractor with the engine rated power of 50 kW (0.037 to 0.077 l/tkm), the highest consumption with the tractor with the rated engine power of 114 kW (0.056 to 0.093 l/tkm). The lowest transport performance on the measured route was found in the combination with the tractor with the engine rated power of 63 kW (19.37 t/h), the highest performance with the tractor with the rated engine power of 114 kW (43.42 t/h).

Keywords: engine characteristics; transport; rated power; fuel consumption; performance

The diesel fuel consumption affects the costs of transport in a significant manner. All measures leading to its minimization are therefore important. The proper formation of the transport combinations is one of such measures, i.e. selecting the power traction means to the trailer whose engine will run in the optimum working regime most of the time in the course of the transport operation, when its specified fuel consumption achieves low values.

Vitlox and Michot (2005) dealt with the effect of the rated engine power utilization on the specific fuel consumption when cultivating soil with rotary harrows. They found that, when using rotary harrows with the 3 m engagement and 4 km/h working speed, the input power was 24 kW and the specific fuel consumption was 330 g/kWh. If the working speed increased to 7 km/h and the engagement to 4.5 m while all other parameters remained unchanged, the input power was 65 kW, however, the fuel consumption decreased to 242.5 g/kWh.

Bauer *et al.* (2006) give an example of an engine running in two regimes at the same 150 kW power output, but at different speeds. In the first regime, the engine runs at 2000 min^{-1} and the fuel consumption is 230 g/kWh, in the second regime, it runs at 1770 min^{-1} and the fuel consumption is 210 g/kWh. The difference in the hourly consumption between both regimes is therefore 3.7 l/h. With the diesel fuel price of CZK 27 per litre, the difference is 100 CZK/h in fuel costs.

MATERIAL AND METHODS

The goal of this work was the determination of how the change of the tractor engine rated power in a transport combination affects the diesel fuel consumption related to the unit of the transport output (l/tkm) and the transport performance (t/h) in the conditions of a mountainous region.

First, a theoretical analysis of the diesel fuel consumption was carried out according to the available literature references when using different engine power in the tractor-trailer working combinations.

The measurement was carried out in the territory of the Šumava Nicov farm which is situated in the sloping

Supported by the Ministry of Agriculture of the Czech Republic, Project No. 1G58055.

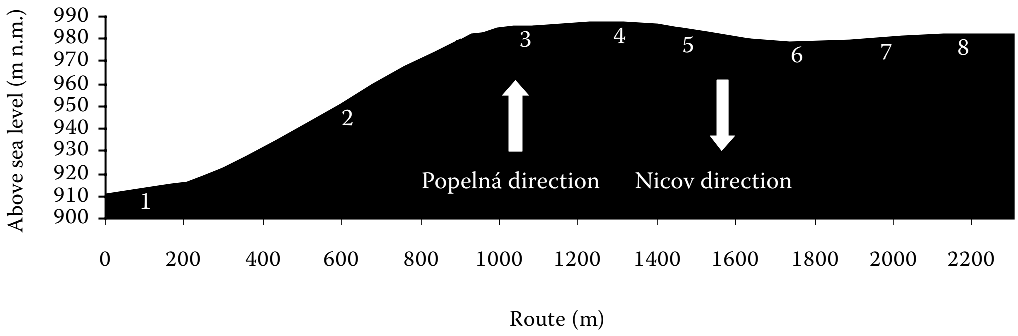

Figure 1. Longitudinal profile of the surveyed route and individual partial sections

territory of the Šumava Protected Landscape Area. The farm cadastre is in the mountainous region.

The route along which the measurement was carried out was surveyed on the asphalt road 2330 m long with the longitudinal profile indicated in Figure 1. The longitudinal profile of the route was established by measuring the above sea levels with a digital altimeter in 50 m distances. The measurement itself was carried out in 8 sections of the same gradient that were surveyed on the route. The parameters of these sections are given in Table 1.

The Zetor 7745 Case IH JX90U and Case MX 150 tractors were chosen for the measurement. The basic parameters of these tractors are given in Table 2. The EDM 1404 flow meters were installed in the fuel systems of these tractors.

Table 1. Positions and inclination of individual sections with the beginning at Nicov

Section number	Section interval (m)	Incline (°)
1	0–300	2.1
2	300–900	5.5
3	900–1200	1.3
4	1200–1400	0.0
5	1400–1650	–1.6
6	1650–1847	–0.3
7	1847–2085	0.7
8	2085–2300	0.0

For the determination of the conditions of the engines of the tractors used, the characteristic of the engine revolution was determined on a dynamometer and the rated engine power indicated by the manufacturer was verified. A plot was constructed for these tractors of the dependence of the effective specific fuel consumption (g/kWh) on the engine rated power (%).

The P93S tipping trailer (Table 3) was used as the trailer. This made it possible to form three transport combinations of the same load carrying capacity that differed by the engine power of the tractors used. The trailer tyres were pressurised to the pressure of 400 kPa as prescribed by the manufacturer.

The trailer was first loaded with 5.8 t and then with 10.2 t of sand. The trailer dead load, the load mass and the dead load of the tractors were determined by the Haeni WL 103 hydraulic portable balance.

The specific pressure of the trailer tyres on a hard base was determined during the highest load mass according to ČSN and the coefficient of the design fullness was determined.

The measurements were carried out during the up hill drive on the surveyed route from Nicov to the Popelná village (designated as the Popelná direction) and during the down hill drive from The Popelná village to Nicov (designated as the Nicov direction).

The assessed data were determined for the transport return, i.e. for driving in one direction without load and with load. The indicated drive direction (Popelná or Nicov) determines the drive in the given

Table 2. Basic technical data of the tractors Zetor 7745, Case III JX90U and Case III MX150

Date	Zetor 7745	Case III JX90U	Case III MX150
Year of production	1988	2003	2001
Engine rated power (kW)	50	63	114
Dead load (t)	3.9	4.5	8.3
Tires – front axle	BARUM 11.2-24	TAURUS 13.6 R 24	CONTINENTAL CONTRACT AC 85 420/85 R 28
Tires – rear axle	BARUM 16.9-30	TAURUS 16.9 R 34	KLÉBER TRACKER 520/85 R 38 20.8 R 38

Table 3. Basic technical data of the P93S trailer

Date	Value
Trailer load (t)	9
Dead load (t)	2.06
Tires – leading axle	BARUM 12.5-18 ZS
Tires – rear axle	BARUM 12.5-18 ZS

direction with load, the drive in the opposite direction was without load.

RESULTS

Theoretical analysis

The theoretical analysis of the diesel fuel consumption was carried out during various performances of the working tractor – trailer combinations.

Relation (1) for the calculation of Q_h, the hourly fuel consumption of tractors, is valid for the new design concepts of tractors in the case when the engine runs in the optimum working regime:

$$Q_h = 0.336 \times P_j^{0.938} \times \varepsilon_j^{0.781} \quad \text{(l/h)} \qquad (1)$$

where:
P_j – engine rated power (kW)
ε_j – usage of the engine rated power (%)

According to Bauer *et al.* (2006), the hourly fuel consumption can be calculated according to Eq. (2)

$$Q_h = \frac{P_e \times m_{pe}}{\rho_p} \times 10^{-3} \quad \text{(l/h)} \qquad (2)$$

where:
P_e – effective engine power output (kW)
m_{pe} – effective specific fuel consumption (g/kWh)
ρ_p – specific fuel mass (kg/l)

If the effective specific fuel consumption m_{pe} is expressed from Eq. (2) and the hourly fuel consumption Q_h is substituted into Eq. (1), we obtain Eq. (3) during the usage of the mere traction force of the tractor:

$$m_{pe} = \frac{(0.336 P_j^{0.938} \times \varepsilon_j^{0.781})\ \rho_p}{P_e} \times 10^{-3} \text{ (g/kWh)} \qquad (3)$$

After substituting the corresponding values, the graph in Figure 2 was set up by means of Eq. (3).The calculation was carried out for the tractors used for the measurements. It is obvious from the graph that the effective specific fuel consumption decreases according to the equation indicated in the graph with the increasing usage of the rated engine power.

Determination of the rated power of the engines

The characteristics of the engine revolution and the rated powers of the engines of the three tractors monitored were determined by means of a mobile dynamometer. For Case 150MX, values smaller by 3 kW were measured compared with the manufacturer's values, for Case JX90U they are the same, and for Zetor 7745 are smaller by 8 kW. This difference is caused by the tractor age and its worse technical condition. A plot of the dependence of the effective specific fuel consumption (g/kWh) on the usage of the rated power output of the engine (%) was constructed for the Zetor 7745 and Case IH MX 150 tractor using the measured values. The usage of the engine rated power in Figure 3 was rated as the ratio of the effective engine power output and the engine rated power. These values were measured by a mobile dynamometer. The results are indicated in Figure 3. It is obvious from the comparison of the effective specific fuel consumption (m_{pe}) determined by calculation (Figure 2) with the values measured that the higher values of the effective specific consumption in the

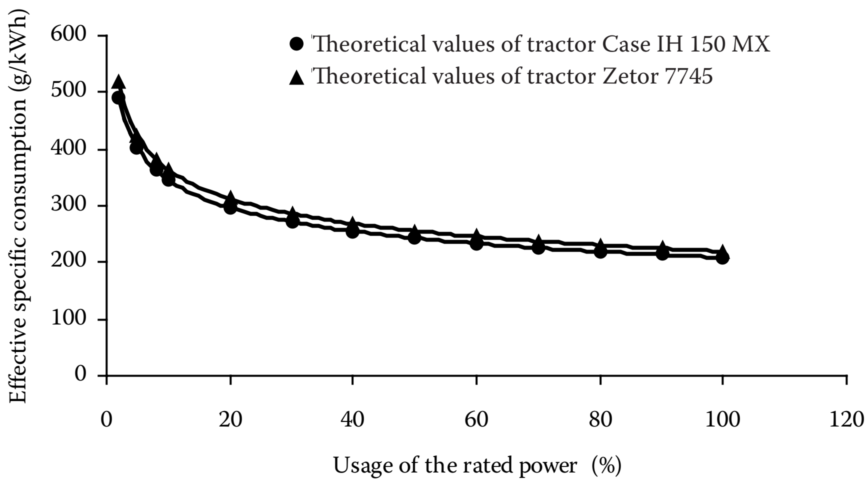

Figure 2. Dependence of the effective specific fuel consumption (g/kWh) on the usage of the engine rated power (%) determined by teoretical calculation for tractors with the 50 and 114 kW rated power

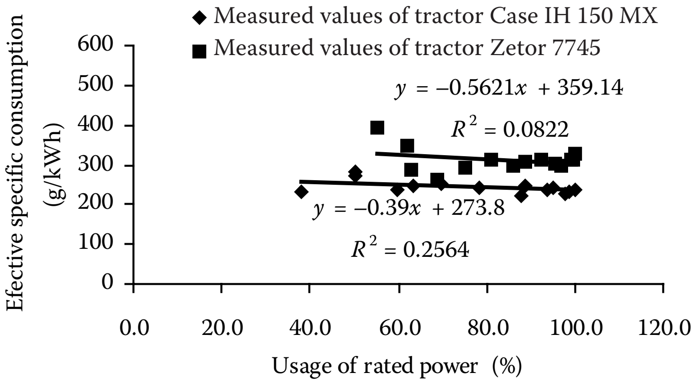

Figure 3. Dependence of the effective specific fuel consumption (g/kWh) on the usage of the engine rated power (%) determined by measuring in the Case 150 MX and Zetor 7745 tractors

Zetor 7745 tractor determined by the measurement are due to the older engine concept and its higher wear out.

Specific pressures of the trailer tyres on the hard base and the coefficient of the design fullness

The specific pressure of the tyres on the hard base was 596 kPa at the 10.2 t load mass and the average coefficient of the design fullness 64%. This value corresponds to the recommended approximate values in the 55% to 60% range.

Diesel fuel consumption per unit of the transport performance

The results of the measurement of diesel fuel consumption were converted into the units of the transport performance; they are given in Figure 4. Columns 1 (direction Popelná) illustrate the consumption during the up hill drive with load and the down hill drive without load. On the contrary, columns 2 (direction Nicov) illustrate the consumption for the down hill drive with load. By comparing the values of both columns, the effect can be determined of the drive direction with load on the fuel consumption in the inclined region.

The differences in the consumption in the ascending and descending drive with load are approximately the same for all three tractor-trailer combinations. The differences are a little higher (0.017 to 0.020 l/tkm) for the 10.2 t mass of the transported load than for the 5.8 t mass of the transported load (0.014 to 0.019 l/tkm).

More distinct are the differences in the diesel fuel consumption between the individual transport

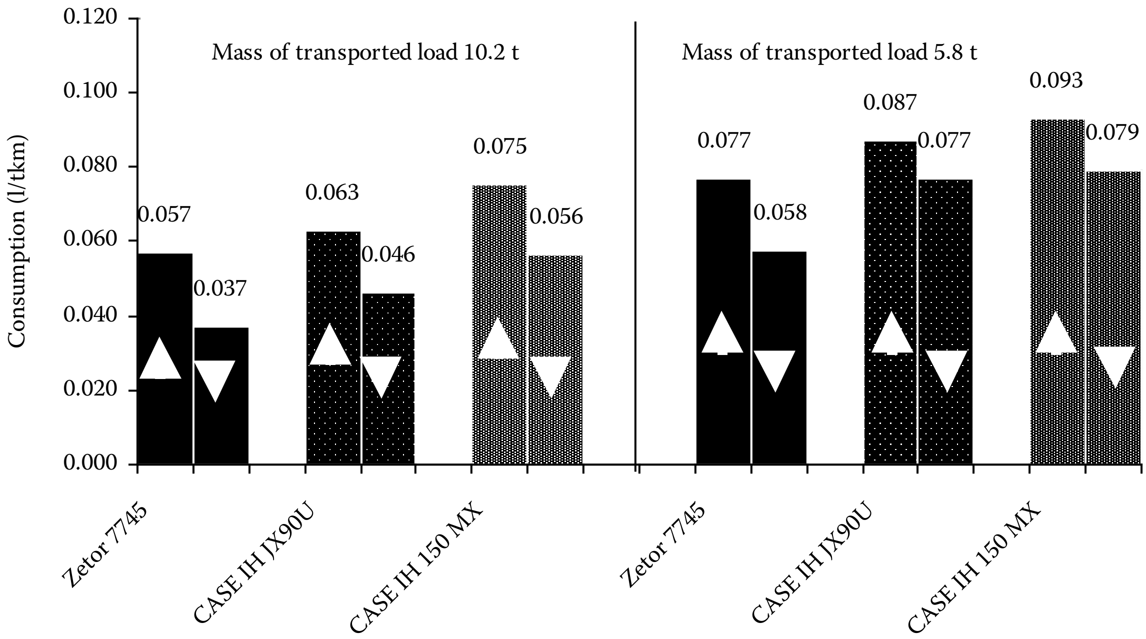

Figure 4. Specific diesel fuel consumption during the transport of material with the 10.2 t and 5.8 t mass along the route with the 70 m superelevation and length 2300 m; the first column depicts the specific diesel fuel consumption for the "Popelná direction" (+70 m), the second column depicts the specific consumption for the "Nicov direction" (–70 m)

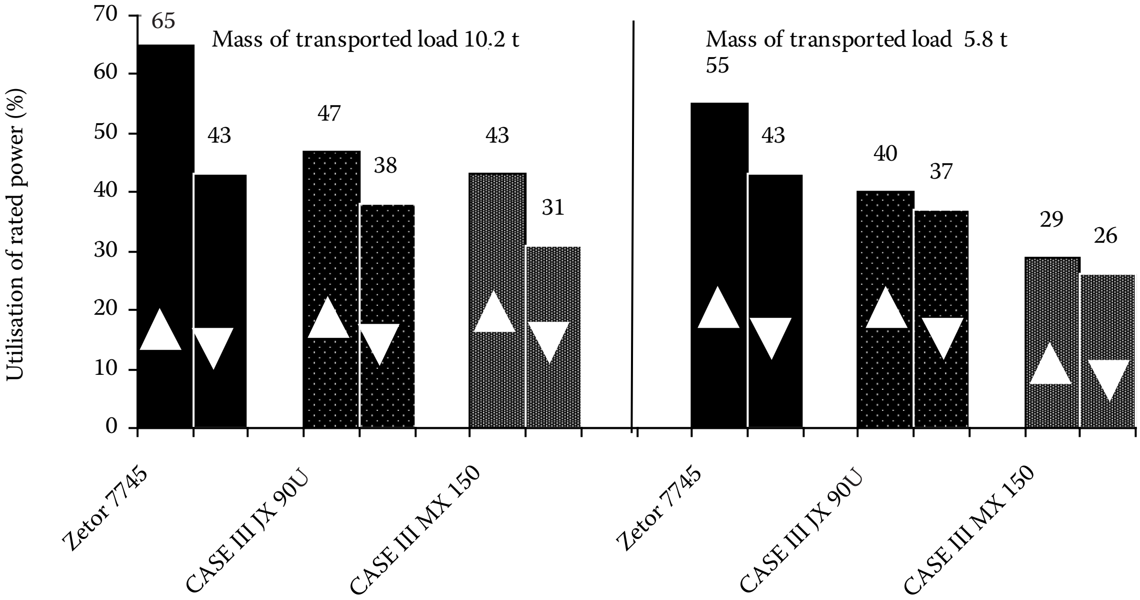

Figure 5. Average engine power utilisation (%) during the transport of material with the 10.2 t and 5.8 t mass along the route with the 70 m superelevation and length 2300 m; the first column depicts the engine power utilisation for the "Popelná direction" (+70 m), the second column depicts the specific consumption for the "Nicov direction" (–70 m)

combinations. The transport combination with the tractor with the 50 kW rated engine power has the lowest consumption, the tractor with the 114 kW rated engine power has the highest consumption. It is obvious from the data in Figure 4 that the tractor engines with the higher rated power are less utilised and are therefore in the region of the working regime with a higher specific fuel consumption. This is also documented by the values in Figure 5, which indicates the utilisation of the rated engine power of the tractors used.

It follows from these facts that of the three tractors used, the tractor with the 50 kW rated engine power is the most suitable for the combination with the P93S tilting trailer under the given conditions and, from the point of view of the diesel fuel consumption, for the transport of material with a mass of 5.8 and 10.2 t.

With the growing rated engine power of the tractor, the diesel fuel consumption per unit of the transport performance increases, as illustrated in Figure 6.

With the increasing route ascent, the demands of the transport combinations increase. The tractor engines with a higher engine power then work in more favourable regions of the working regime with respect to a better utilisation of their rated power and the specific consumption per unit of the transport performance is below the values of tractors with a smaller engine rated power. This is

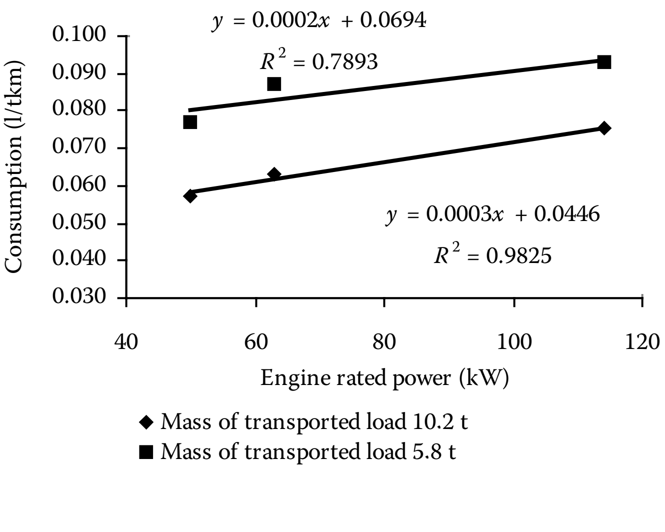

Figure 6. Dependence of the specific diesel fuel consumption (l/tkm) on the tractor engine rated power when driving on level ground (kW) during various masses of transported load

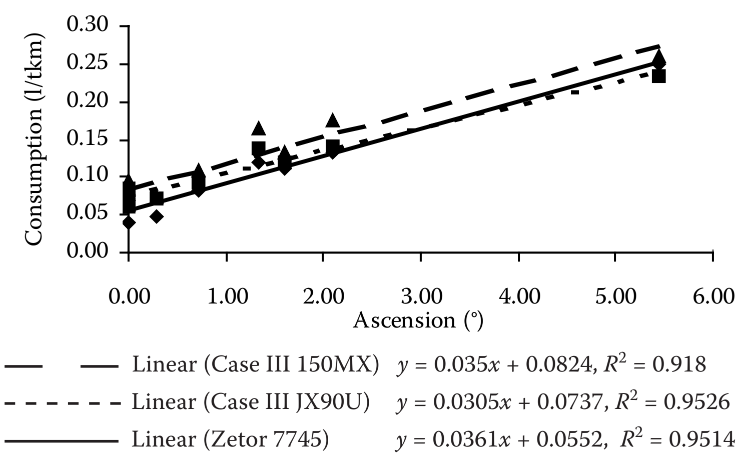

Figure 7. Dependence of the specific fuel consumption (l/tkm) on the driving route ascension when transporting load with the 5.8 t mass

obvious from Figure 7, showing that the specific consumption of the tractor with the 63 kW engine rated power is lower than that of the tractor with the 50 kW engine rated power during the descent drive with the 3.5° gradient. With the increasing mass of the load, the advantages of tractors with a higher engine rated power become more obvious; this is obvious from Figure 8. From the point of view of the specific consumption per unit of the transport performance, the tractor with the 114 kW engine rated power is the most convenient at the 10.2 t mass from the 3.5° descent. The specific consumptions in Figures 7 and 8 were calculated only for the drive with load.

Performance of transport combinations

Besides the mass of the transported material, the performance of the transport combinations depends on the transportation speed of the combination. Besides the highest design speed of the traction power system and trailer and the quality of the route surface, it is primarily the engine rated power of the traction system that affects the transportation speed of the tractor-trailer combination. For this reason, tractors with a higher engine rated power achieve higher transportation speeds. If the difference in the rated power is small, the driver's technique of driving may be more important for the transport performance achieved on a given transport route than the difference in the engine rated power. This is also obvious from Figure 9, where the differences in the transport performances between the tractor-trailer combinations with the 50 kW and 63 kW engine rated powers are negligible. However, the higher transportation speed of the combination with the tractor with the 114 kW engine rated power affects the achieved performance significantly. The transport performance depends also on the direction of the tractor-trailer drive with load – ascending

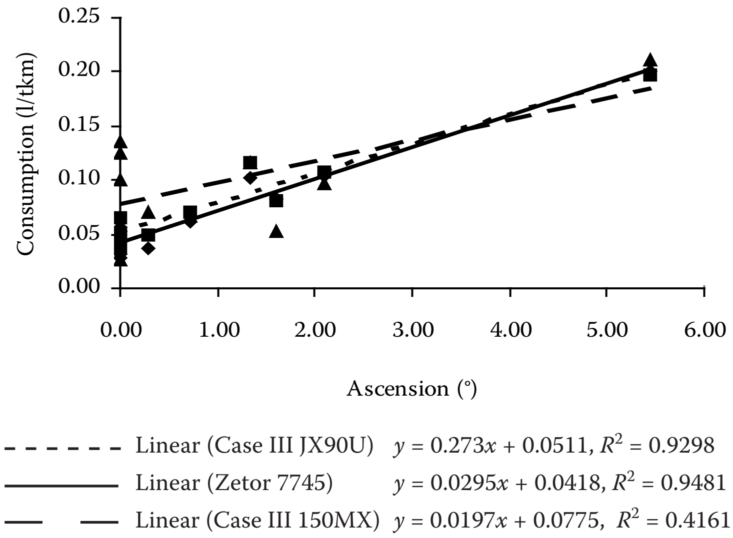

Figure 8. Dependence of the specific fuel consumption (l/tkm) on the driving route ascension when transporting load with the 10.2 t mass

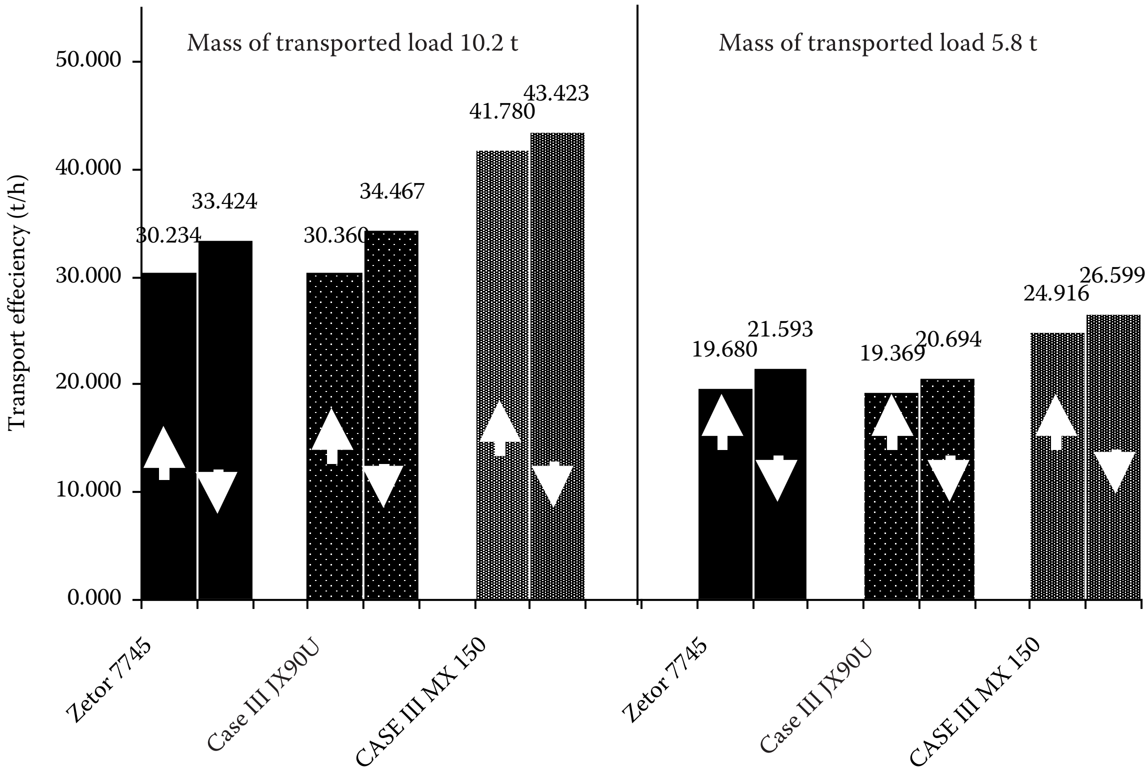

Figure 9. Transport performance when transporting material with the 10.2 t and 5.8 t mass along the route with the 70 m superelevation and length 2300 m. The first column depicts the transport performance for the "Popelná direction" (+70 m), the second column depicts the specific fuel consumption for the "Nicov direction" (–70 m)

(columns 1 in Figure 9) or descending (columns 2). However, the difference is not significant.

DISCUSSION AND CONCLUSIONS

By measuring the transport combinations formed by tractors with the 50, 63 and 114 kW engine rated power with the tipping trailer with the 5.8 and 10.2 t loads in the inclined region, the specific diesel fuel consumptions related to the unit of the transport performance were determined.

Under the conditions of measurement, the specific consumption in the transport cycle (drive with and without load) was between 0.058 and 0.093 l/tkm at the 5.8 t mass of the transported material, and between 0.037 and 0.075 l/tkm at the 10.2 t mass of the transported material. The lowest specific consumption on the measured route was found for the combination with the tractor with the engine rated output of 50 kW (0.037 to 0.077 l/tkm), the highest consumption with the tractor with the rated engine output of 114 kW (0.056 to 0.093 l/tkm).

Under the given conditions, the tractor-trailer performance in the transport cycle (drive with and without load) was between 19.37 and 26.6 t/h at the 5.8 t mass of transported material, and between 30.23 and 43.42 t/h at the 10.2 t mass of transported material. The lowest transport performance on the measured route was found for the combination with the tractor with the engine rated output of 63 kW (19.37 t/h), the highest performance with the tractor with the 114 kW rated engine output (43.42 t/h).

It follows from these measurements that, if we wish to achieve diesel fuel savings during the transport operations, it is important to decide what tractor or, as the case may be, means of transport will be used, not only with respect to the tractor engine power but also to the transported volume of material and the terrain relief.

References

Bauer F. *et al.* (2006): Traktory. 1st Ed., Profi Press, s.r.o., Praha.

Vitlox O., Michot B. (2005): Energy consumption in agricultural mechanisation. The Hague, Agricultural Economics Research Institute. Available at http://www.lei.dlo.nl/publicaties/pdf/2000/2_xxx/2_00_01_1.pdf. (accesed April 24, 2007)

Received for publication June 27, 2007

Accepted after corrections August 2, 2007

Abstract

Jílek L., Pražan R., Podpěra V., Gerndtová I. (2008): **Vliv využití jmenovitého výkonu motoru traktoru na spotřebu motorové nafty při přepravě materiálu**. Res. Agr. Eng., **54**: 1–8.

Autoři článku při terénním měření stanovili, jak se změna výkonu motoru traktoru u dopravní soupravy projeví ve spotřebě motorové nafty vztažené k jednotce přepravního výkonu (l/tkm) a na přepravní výkonnost (t/h) v podmínkách horské oblasti. Porovnány byly dopravní soupravy vytvořené sklápěcím přívěsem postupně připojovaným ke třem traktorům o různém výkonu motoru při průjezdu trasy o sklonu 0°–5,5°. Z výsledků měření je patrné, že se spotřeba nafty jednotlivých souprav liší až o 27 %. Nejnižší měrnou spotřebou na měřené trase měla souprava s traktorem o jmenovitém výkonu motoru 50 kW (0,037 až 0,077 l/tkm), nejvyšší souprava s traktorem o jmenovitém výkonu motoru 114 kW (0,056 až 0,093 l/tkm). Nejnižší přepravní výkonnost na měřené trase měla souprava s traktorem o jmenovitém výkonu motoru 63 kW (19,37 t/h), nejvyšší souprava s traktorem o jmenovitém výkonu motoru 114 kW (43,42 t/h).

Klíčová slova: charakteristika motoru; přeprava; jmenovitý výkon; spotřeba paliva; výkonnost

---

Corresponding author:

Ing. Ladislav Jílek, Anser, s.r.o., Bažantní 697, 165 00 Praha 6-Suchdol, Česká republika
tel.: + 420 233 920 254, fax: + 420 233 920 255, e-mail: anser@volny.cz