Influence of engine power and shifting mode on energy-performance parameters of tractor's set

J. Čupera, T. Šmerda

Faculty of Agronomy, Mendel University in Brno, Brno, Czech Republic

Abstract

Čupera J., Šmerda T., 2010. **Influence of engine power and shifting mode on energy-performance parameters of tractor's set**. Res. Agr. Eng., *56*: 47–52.

The aim of the paper is to assess the impact of engine power and shifting mode on the parameters of a tractor used in transport operation. To meet the objective, measurements were performed with three tractors of the Case IH product line with different maximum power and with the same trailer and load that crossed a track with 21,8 km of distance. The record files saved following values: altitude, time of trip, tractor velocity, hour fuel consumption, engine speed, actual engine torque, fuel temperature, and position. The measurement results clearly show the unsuitability of aggregation of a tractor in higher performance category, resulting in the increase in its fuel consumption does not increase performance. To improve the utilization of powerful tractors, it is necessary to reduce their weight and aggregate them with more axles on the trailers in order to better use the potential power caused by possibility of more load.

Keywords: transport; engine; tractor; fuel consumption; performance

Agricultural transport is characterized by diversity of transported material and distance of transport routes, which may reach up to 35 km outside of the corporate transportation. There is also a wide range of techniques to ensure material flow. Energy means that tractors must be used as universal machinery which is aggregated with a trailer or semitrailer with possibility of swap bodies. Operating characteristics of sets affect mainly the power needs of the engine, the tractor weight, weight distribution, stability and controllability (Semetko et al. 1986). For the aggregation of tractors there are usually chosen types with different maximum engine power from 100 to 300 hp, it may lead to questions if the power of the engine will have an effect on the resulting transport parameters, particularly performance and hour fuel consumption. These issues were also researched by Semetko et al. 1986, Stadler et al. 2004, Syrový 2006, or Weise, Engelhardt 1999, Weise 2000, Jílek et al. 2008, their work was focused on comparison of the cargo and tractor traffic.

Power balance formula shows which parts of the performance are consumed to overrun the resistance, its size can be generally expressed by following equation:

$$P_e = P_m + P_o + P_v \pm P_s + P_a + P_w \ \text{(W)} \quad (1)$$

where:

P_e – effective engine power (W)
P_m – engine loss in transmission (W)
P_v – power to overcome the rolling resistance (W)
P_s – power to overcome the climbing (W)

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. COST 356 OC191 and No. MSM 6215648905.

P_o – power to drive of support devices (pumps etc.) (W)
P_a – power to overcome the inertia (W)
P_w – power to overcome the air drag (W)

The Eq. (1) can be overwritten as follows:

$$P_e = \frac{\left(F_v \times v_s \pm F_s \times v_s + F_a \times v_s + F_w \times v_s\right)}{\eta_m} + P_o \quad \text{(W)} \qquad (2)$$

where:
F_v – rolling resistance (N)
F_s – force of climbing drag (N)
F_a – inertia force (N)
η_m – mechanical efficiency (–)
v_s – actual velocity (m/s)

Thus, it is clear that the power of the engine affects the size of running speed and results the performance of the combination.

MATERIALS AND METHODS

To meet the objective, measurements were performed with three tractors of Case IH product line with different maximum power. Technical specifications of tractors are given in Table 1. Tractors were aggregated with the same trailer Annaburger HTS 22.79. Semi-trailer was loaded with the soil mass about 15,400 kg and its total weight reached up to 23,640 kg. The track distance reached up to 21.8 km in total and was divided to 8 sub-sections with plane and hill profile (Fig. 1). All sets were driven by the same driver, who was familiar with the settings for each of tested tractors. Fundamental parameters of recorded file were obtained by CAN-Bus monitoring (actual velocity of tractor, actual fuel consumption, engine speed, engine load and torque, fuel temperature) and by external measuring of analog inputs (calculated altitude). The location of a set was determined by GPS receiver. Main sample rate was set to 5 S/s.

Field instrumentation is distributed and includes three basic parts:
- data collection from internal CAN communication network via PCMCIA card of National Instruments,
- analog inputs consist of signal from pressure sensor and input voltage,
- localization by GPS module.

CAN-Bus monitoring

CAN-Bus monitoring was required for driving cycle determination. The CAN-Bus of all tractors were fully compatible with SAE J1939 in the extended ArbID (29 bit). The communication speed was 250 kbps. Relevant messages were selected for next evaluation and analyses.

Altitude measurement

Altitude measurement was carried out using a pressure sensor (Motorola MPX4115) measured in the range of 15–115 kPa. The output signal is linear in the range of 0.2 to 4.8 V. Pressure measurement accuracy is 1.5%. Calibration was provided at the triangular point (with known altitude). The uncer-

Table 1. Testing tractors Case IH

Type	CVX 195	MAGNUM 225	MAGNUM 310
Tractor number	Z7SDO2074	ZTRZ02805	ZTRZO2466
Year of manufacturing	2007	2007	2007
Working hours	26.3	8.9	45
Rated engine power (kW) (ECE R 120)	159 kW*	189 kW	254 kW
Transmission	Continuously variable transmission	Powershift 19 × 6 ECO	Powershift 19 × 6 ECO
Weight (kg)	8,160	10,400	13,300
Tire – front	Continental 540/65 R30	Michelin 540/65 R34	Michelin 540/65 R34
rear	Continental 650/65 R42	Michelin 650/85 R38	Michelin 650/85 R38

*power boost

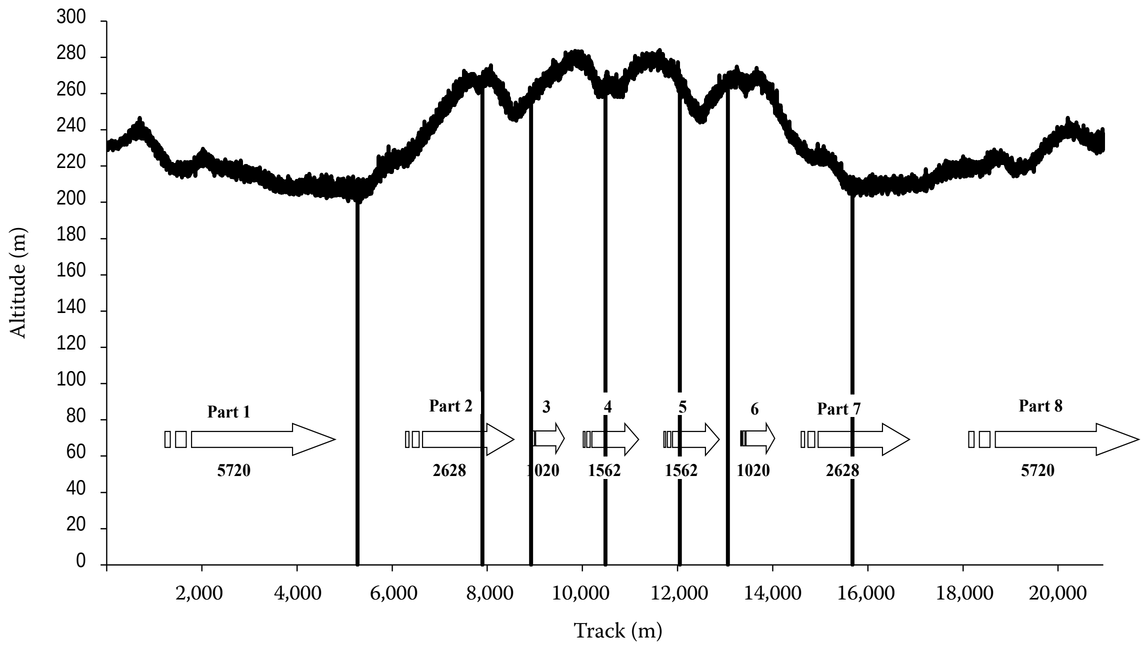


Fig. 1. Altitude of track

tainty of altitude did not cross 0.5 m. The signal was processed by the USB DAQ card from National Instruments production.

GPS module

Additional data formed a matrix from GPS module, commercial Garmin GPS module with data output via RS 232 and 1 s response time was used.

Evaluation was done for all parts individually and for the entire track. From measured values following parameters were calculated.

Averaged fuel consumption for a part of track:

$$Q_p = \frac{\sum_{i=1}^{n} q_i}{T \times f} \quad \text{(l/h)} \tag{3}$$

where:

q_1 – actual fuel consumption (l/h)

T – time for driving through an evaluated part of track (s)

f – sample rate (S/s)

Total fuel consumption for a part of testing track:

$$Q = \frac{\sum_{i=1}^{n} q_i \times T}{3.6 \times 10^3 \times n} \quad \text{(l)} \tag{4}$$

where:

n – total count of sample (–)

Average velocity of set

$$v_p = \frac{\sum_{i=1}^{n} v_i}{T \times f} \quad \text{(km/h)} \tag{5}$$

where:

v_1 – actual velocity of set (km/h)

Effective performance

$$W_t = \frac{G_n}{T} \times 3.6 \times 10^3 \quad \text{(t/h)} \tag{6}$$

where :

G_n – weight of load (t)

Drive mode was selected so that tractor could load either in the area with maximum engine power or in field near maximum engine torque, where the lowest fuel consumption is expected. Dividing testing track to eight separate parts can offer a possibility to evaluate each set under various conditions when climbing or running on a flat road.

Overall six measurements were carried out:

CASE IH CVX 195 + ANNABURGER HTS 22.79

- CVX2 – load potentiometer setting to 10 (economic drive)
- CVX3 – load potentiometer setting to 5 (maximum engine power)

CASE IH Magnum 225 + ANNABURGER HTS 22.79

- MAGNUM1 – automatic gear shifting (maximum engine power)
- MAGNUM2 – manual gear shifting (economic drive)

CASE IH Magnum 310 + ANNABURGER HTS 22.79

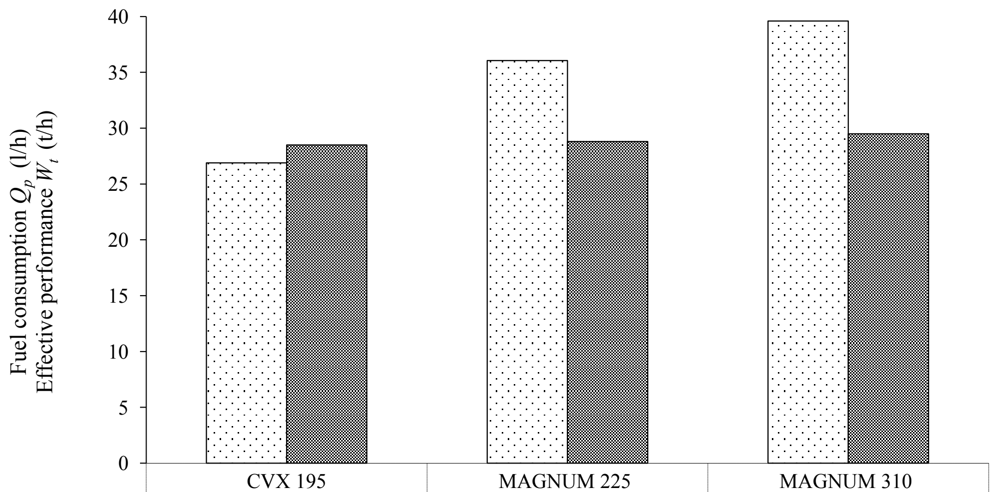
- MAGNUM1 – manual gear shifting (maximum engine power)
- MAGNUM2 – manual gear shifting (economic drive)

Measured values were processed and evaluated by means of MS Excel and Matlab 9. Traffic performance was calculated as well as other important parameters, e.g. hour and specific fuel consumption as the most important aspect of possible savings in use. Outcomes were processed into bar charts (Figs. 2–5)

RESULTS AND DISCUSSION

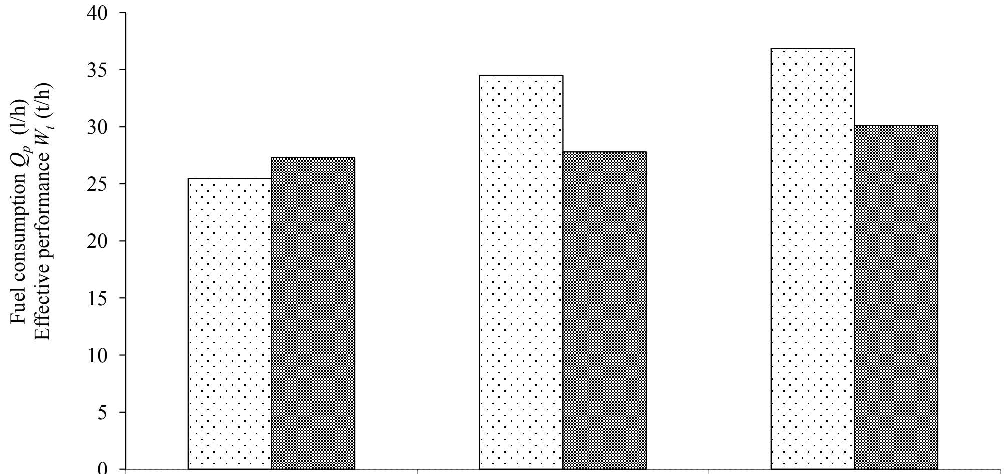
The aim of the measurements has been to determine how traffic parameters of a tractor in transport use can be affected when gear shifting mode forced engine operation to different parts of its speed map. For this purpose, three sets with the same trailer and load were used. Aggregated tractors were different in their engine power as well as in its curb weight. Uphill movement and drive across the track were selected for evaluation. Climbing causes overload of engine and the highest impact on monitored parameters can be thus expected. The drive on a flat road does not allow using power potential of traffic performance as the maximum speed is limited to 40 kph.

The change can be seen in fuel consumption caused by different weight of tractors. Engine power is needed when driving uphill because of the growing resistance components (Eq. 2). Tractors with a higher engine power may operate with a lower gear ratio due to high torque, and moreover they can run at higher speeds. This is also confirmed by the results of measurements listed in Fig. 4. The CVX 195 tractor had the lowest performance when climbing. If the CVX 195 is taken as the base, then compared with the Magnum 310 traffic performance will decrease about 18.2 t/h (10.1%) but hour fuel consumption will fall down to 16.77 l/h (43.19%). This means an inadequate increase in fuel consumption with small increase in performance sets, in other words if the performance increases by 1 t, it will take 0.92 l of fuel more. The drive mode of the CVX 195 tractor focused on the lowest fuel consumption brings a decrease in performance by 18.5 t/h (11.4%) and fall in hour fuel consumption of 5.15 l/h (15.2 %). In other words if the performance grows about 1 t, then it will take 0.28 l of fuel more. The ideal case would be if the increase in performance corresponds to the same or a lower growth in fuel consumption. It primarily depends on the course and size of the fuel consumption and engine power in speed characteristics and size of the loss resistance. If the gear shifting is chosen to achieve the lowest fuel consumption, then it will cause a fall in performance according to lower engine power. The greatest fall in fuel consumption



	CVX 195	MAGNUM 225	MAGNUM 310
Fuel consumption	26.89	36.06	39.59
Effective performance	28.5	28.8	29.5

Fig. 2. Drive across the entire track, drive mode was chosen to the maximum engine power



	CVX 195	MAGNUM 225	MAGNUM 310
□ Fuel consumption	25.47	34.51	36.87
▩ Effective performance	27.3	27.8	30.1

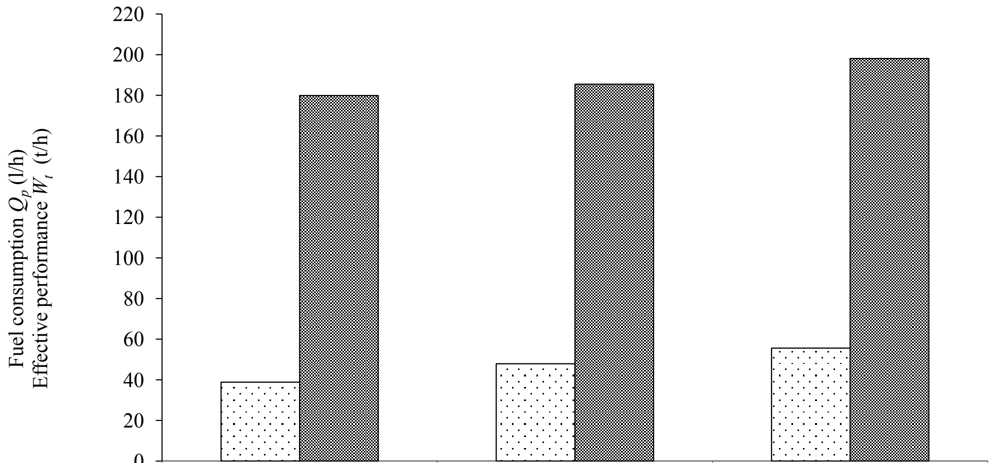
Fig. 3. Drive across the entire track, drive mode was chosen to the lowest fuel consumption

was found with the CVX 195 tractor and was caused by differential hydrostatic transmission which allows keeping the engine speed in the highest torque area of operation. This manner cannot be achieved by using manual gearbox, particularly in the case of a tractor with high torque, as was Magnum 310. The results of driving across the entire track are following: the CVX 195 tractor in comparison with Magnum 310 brought a decrease in performance by 4 t/h (14%) but the fuel consumption declined to 12.7 l/h (47.2%). This means the increase in performance by 1 t consumes 3,175 l of fuel.

Comparing the CVX 195 itself in both modes of driving cycles shows growth in performance by 1.2 t/h (4.4%), however the fuel consumption also grew up by 1.42 l/h (5.5%). Thus the increase in performance by 1 t uses 1.18 l of fuel more.

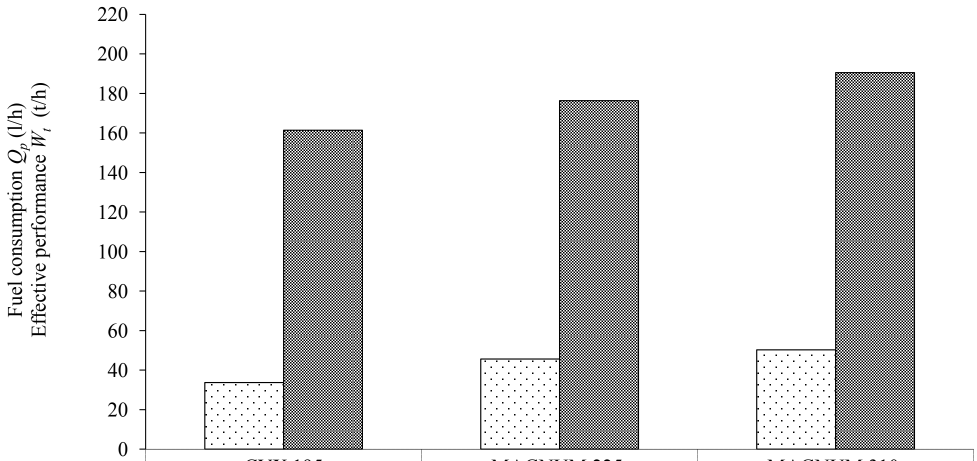
CONCLUSION

The results clearly show the unsuitability of aggregation of tractors in higher performance category in transport use. An increase in its fuel consump-



	CVX 195	MAGNUM 225	MAGNUM 310
□ Fuel consumption	38.82	47.9	55.59
▩ Effective performance	179.9	185.4	198.1

Fig. 4. Drive across the second part of track (uphill), drive mode was chosen to maximum power



	CVX 195	MAGNUM 225	MAGNUM 310
□ Fuel consumption	33.67	45.59	50.24
▩ Effective performance	161.4	176.3	190.5

Fig. 5. Drive across the second part of track (uphill), drive mode was chosen to the lowest fuel consumption

tion does not bring any increase in performance compared to a tractor with a lower power. To improve the use of powerful tractors, it is necessary to reduce their weight and aggregate them with more axles on the trailers in order to better utilize potential power. Some exception can be powerful tractors with hydrostatic transmission differential, which allow setting of the drive to the area with the highest torque along with the lowest specific fuel consumption. The results show that for transport it is appropriate to use tractors with low curb weight and more power, because losses are mainly affected by weight. Measurements also presented the impact of the gear shifting mode on the resulting transport parameters.

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Received for publication August 13, 2009
Accepted after correctons September 21, 2009

Corresponding author:

Ing. Jiří Čupera, Ph.D., Mendel University in Brno, Faculty of Agronomy, Zemědělská 1, 613 00 Brno, Czech Republic
phone: + 420 545 132 942, e-mail: xcupera@node.mendelu.cz