

Effects of tillage systems and wheel slip on fuel consumption

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Abstract: *The high prices of fuel lead to an increasing awareness of energy efficiency in plant production. An Austrian experiment analyses the effect of varying tillage depth on wheel slip, diesel consumption and field capacity. The tractor (92 kW) was equipped with a data-acquisition system for the engine speed, real speed (measured with radar-sensor), theoretical speed (measured with an inductive-sensor from the gear wheel) and fuel consumption (measured with an integrated flow-meter in the fuel system). A 2x4 mouldboard plough (two-way rear mounted) of 1.70 m working width and an heavy cultivator (subsoiler - 3 m working width) was used to investigate the influence of four wheel drive, speed and working depth on slip and fuel consumption. The results show that the wheel slip is a critical parameter for fuel consumption and field capacity. Due the four wheel drive the slip could be reduced in the case of plough from 6 to 3 % which means 2 l/ha reduced diesel consumption. In the case of the heavy cultivator the wheel slip could be reduced from 15 % to 5 % which means also 2 l/ha reduced diesel consumption. The energy (diesel) input per tonne moved soil bulk decreases with the increasing tillage depth while the total energy input per hectare increases. In the case of plough with an adjusted working depth of 18 cm the energy input per tonne moved soil bulk was 584 Wh. At the working depth of 35 cm the energy input per moved soil mass was 429 Wh.*

Keywords: soil tillage, fuel consumption, wheel slip, four wheel drive

1. Introduction

Due to increasing fuel prices, energy efficiency in plant production became an increasing awareness. In a conventional cropping system the greatest energy consumer is soil tillage. In comparison to conventional cultivation with plough the fuel consumption could be reduced for cultivation at 3 to 4 fold with a no-till systems (MOITZI 2005 [2]). The transition from ploughing to reduced or no-tillage systems requires certain adaptation measurements and awareness training. At time the conventional cropping system with plough is still very common. The transmission of drawbar power via the interface wheel and soil surface is affected of the efficiency of traction which depends on the slip and rolling resistance. The efficiency of traction depends mainly on tractor related factors (weight of the tractor, number of driven axle, kind of tyre, inflation pressure) and soil related factors (surface hardness, soil moisture content). An improvement of drawbar transmission could be reached with an enlargement of the surface between the driven wheel and soil surface. One technical realisation of this aspect is the four wheel drive, which is common in use or using a supplementary driven axle via PTO (PADUREANU ET AL. 2004 [3]).

The requirement of drawbar power in soil tillage depends mainly on the working depth. Approximately 100 m³ or 150 t (soil density: 1.5 kg/dm³) per hectare must be moved if one centimetre soil is tilled. Depending on soil constitution the fuel consumption increases per centimetre ploughing depth between 0.5 and 1.5 l/ha (MOITZI 2005 [2]).

This paper deals the influence of four wheel drive, speed and working depth on slip and fuel consumption during ploughing and cultivating with a heavy cultivator in a representative region for cereal growing in the Eastern part of Austria.

2. Material and method

The experiments were carried out on 3th and 4th November 2005 at the experimental farm of the University of Natural Resources and Applied Life Science (BOKU) in Groß Enzersdorf (Lower Austria). The soil (sandy loam) had a mean gravimetric water content of 14 %, which was relatively low. The mean bulk density (0 – 30 cm) was 1.35 g/cm³. The field (length of 700 m) with chopped maize straw from the previous crop was tillaged with two different machines:



2x4 mouldboard plough – two-way-rear mounted: working width: 1.7 m



Heavy-cultivator (subsoiler) with star distributor and cracker rolls: working width: 3.0 m

For the soil-tillage we used a four-wheel-tractor (Steyr 9125) with an engine power of 92 kW (DIN). The engine with exhaust turbo supercharger has 6 cylinders with a displacement of 6.600 cm³. For the measurement of the fuel consumption a high-performance flow-meter (AVL PLU 116H) with a proportional – integral (PI) – controller was integrated in the fuel system of the tractor. The volumetric fuel consumption was continuously measured with an error rate of 1 % without pressure drop between inlet and outlet ($\Delta p=0$). Additionally an air bubble releaser and heat exchanger (between inlet an outlet fuel) were installed in the fuel measurement system. The digital rectangular signal was logged with a scan rate of 1 Hz. The consumption flow [l/h] is calculated by the followed equation:

$$Q \text{ [l/h]} = \frac{f \times 3.6}{K_D}$$

Q: fuel flow [l/h]

f: frequency [Hz]

K_D: digital calibration factor [1/cm³]; according calibration protocol: 161.99 1/cm³

For the calculation of the slip the parameters “theoretical velocity” (v_0) and the “real velocity” (v) are required. The theoretical velocity was measured inductively with a transmission-sensor (inductively transducer) and was calibrated with an integrated radar sensor in a calibration drive on a slip free asphalt road. The radar-sensor detects the real velocity in a squarewave frequency which is proportional to velocity (27.8 Hz per 1 km/h). The signals of the transmission- and radar-sensor are scanned with 1Hz. The engine speed signal form the inductive-sensor is also scanned with 1 Hz. For signal recording a multi-channel datalogger (Squirrel Datenlogger 2020) was used.

The calculated fuel consumption in l/ha does not consider the fuel consumption during turning at the headland. The parameters in the figures and tables are expressed as median.

3. Results and discussion

3.1 Effects of the 2- and 4-wheel drive

The median fuel consumption per hour during ploughing with 2-wheel drive was 15.2 l. The use of the 4-wheel drive reduced the hourly consumption to 13.5 l (**figure 1**). The realised mean working velocity (v_{radar}) was quite the same: 6.7 km/h respectively 6.8 km/h. The consideration of the median slip showed a reduction from 6 % to 3 %. The fuel consumption per hectare decreased from 13.2 l/ha (2-wheel drive) to 11.5 l/ha (4-wheel drive). This is a result of reduced field capacity due to slip and the higher hourly fuel consumption.

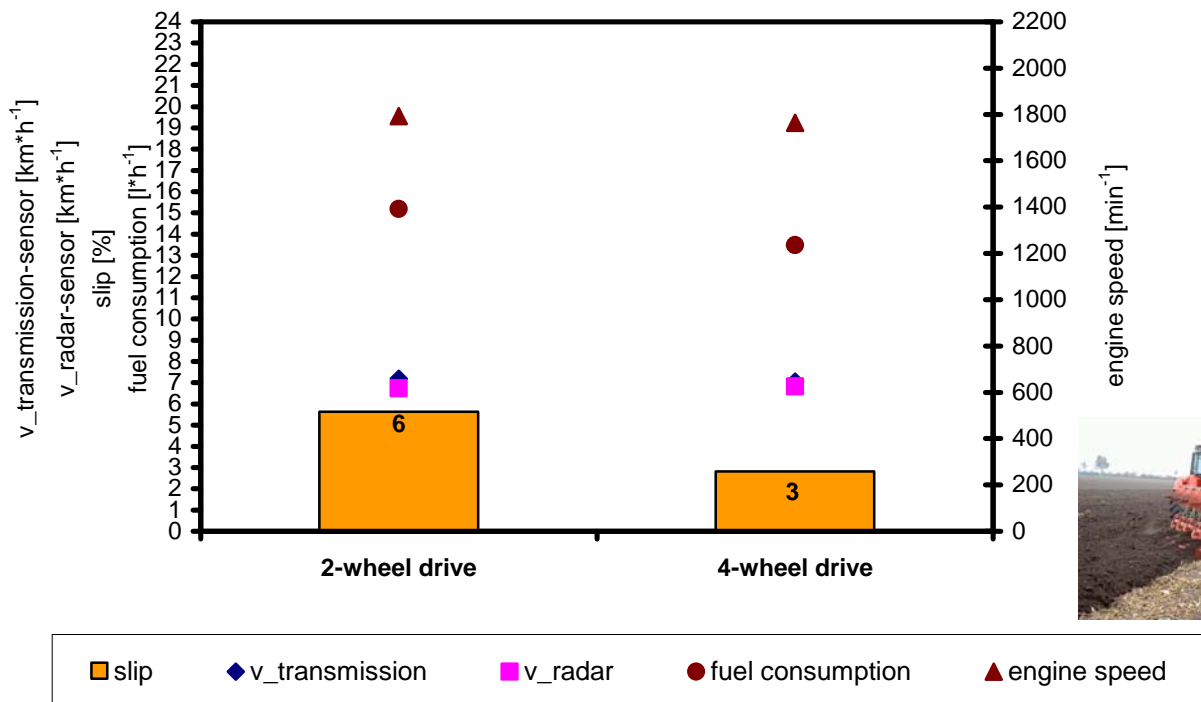


Figure 1: Effects of 4-wheel drive on slip [%] and other parameters during ploughing. (3. gear, 2. power shift); working depth: 15 cm.

Soil tillage with the heavy cultivator was pulled with the same gear adjustment (3. gear, 2. power shift). The hourly fuel consumption was with 2-wheel drive at 22.5 l and with 4-wheel drive at 21.6 l. The median real velocity (v_{radar}) was 7.8 km/h respectively 8.0 km/h. In the trial with the 2-wheel drive the median slip was 15 %. The higher slip at the heavy cultivator was caused by the suboptimal position of the “virtual” drawing point. It could be adjusted by the angle of the upper link. With the 4-wheel drive the slip was reduced to 5%. The calculation of the fuel consumption per hectare showed an increase of 8 l (4-wheel drive) to 10 l (2-wheel drive).

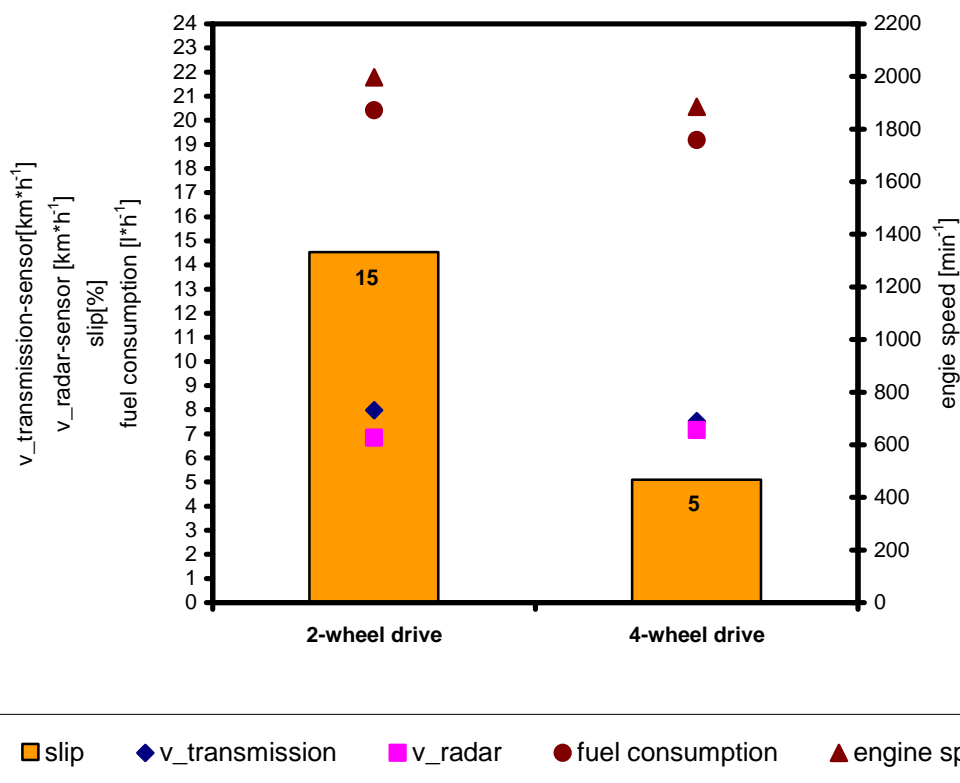


Figure 2: Effects of 4-wheel drive on slip [%] and other parameters during cultivation with a heavy cultivator. (3. gear, 2. power shift); working depth: 15 cm.

3.2 Effects of the working depth

The slip and hourly fuel consumption increased with the working depth during ploughing (**table 1**). The additional demand of drawbar leads to a change of the engine operating point. The hourly fuel consumption increases from 14.6 l at the working depth of 18 cm to 20.7 l at the working depth of 35 cm.

Experiments from FILIPOVIC ET AL. 2004 [1] indicate also an increase of the hourly fuel consumption with the rise of depth of ploughing.

Table 1: Tractor parameters (median) during ploughing; 4-wheel drive (3. gear, 2. powershift)

	v_transmission [km/h]	v_radar [km/h]	slip [%]	engine speed [1/min]	fuel consumption [l/h]
standstill	0	0	0	829	1.99
turning	3.55	3.47	1.50	1068	4.23
working depth	18 cm	6.91	3.34	1732	14.61
	20 cm	7.51	6.03	1873	15.85
	30 cm	7.18	5.68	1804	20.36
	35 cm	7.05	6.12	1773	20.67

In **table 2** the tractor parameters for cultivating with a heavy cultivator are shown. The real velocity was higher than for ploughing because of another gear shifting. This leads also to an higher hourly fuel consumption of about 21.7 l respectively 21.6 l.

Table 2: Tractor parameters (median) during cultivating with a heavy cultivator; 4 wheel drive (3. gear, 3. powershift)

		v_transmission [km/h]	v_radar [km/h]	slip [%]	engine speed [1/min]	fuel consumption [l/h]
standstill		0	0	0	830	2.0
turning		4,05	3.89	1.2	1037	4.24
Working depth	10 cm	9.06	8.63	4.22	1884	21.71
	15 cm	8.52	7.99	5.82	1764	21.55

The mean fuel consumption during turning was about 4.2 l/h for ploughing and cultivation.

3.3 Energy demand per tonne moved soil bulk

The fuel consumption in soil tillage is usually expressed in litre per hectare. It is a relative parameter, which does not consider the working depth. The expression of the fuel consumption on the moved soil bulk describes energy input per soil matter. Figure 3 shows the influence of working depth on the energy respectively fuel consumption per tonne moved soil bulk and per hectare area during ploughing.

The diesel consumption rises at the depth of 18 cm from 12.8 l/ha to 18.3 l/ha at the depth of 35 cm. In contrast, the energy consumption per moved tonne soil bulk decreases from 584 Wh/t to 429 Wh/t. This effect is caused by the degression of the “basic” consumption (for overcoming of the rolling resistance) with increasing amount of moved soil. The “basic” consumption amounts about 7.9 l/ha for ploughing and 5.4 l/ha for cultivating with the heavy cultivator.

Figure 4 displays the results for the heavy cultivator with two working depths. Because of different working depth, it can not be clearly said, that a heavy cultivator causes a lower energy demand for one tonne soil bulk than a plough.

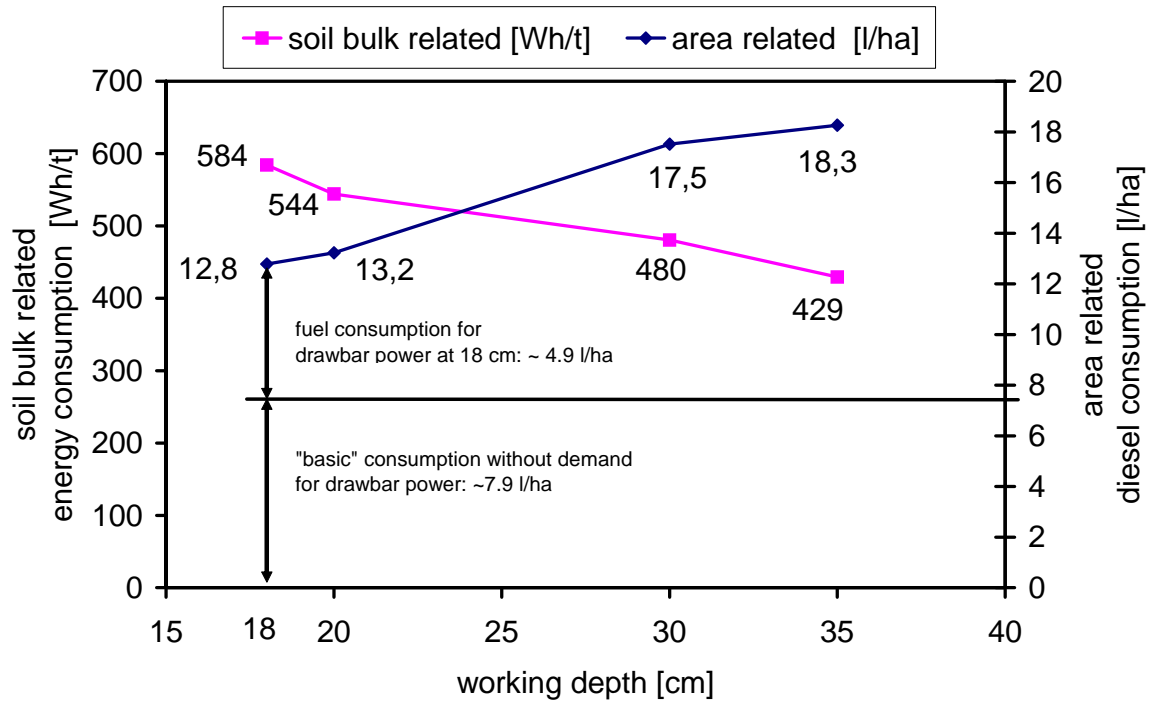


Figure 3: Soil bulk related energy consumption and area related diesel consumption depending on working depth during ploughing (4-wheel drive).

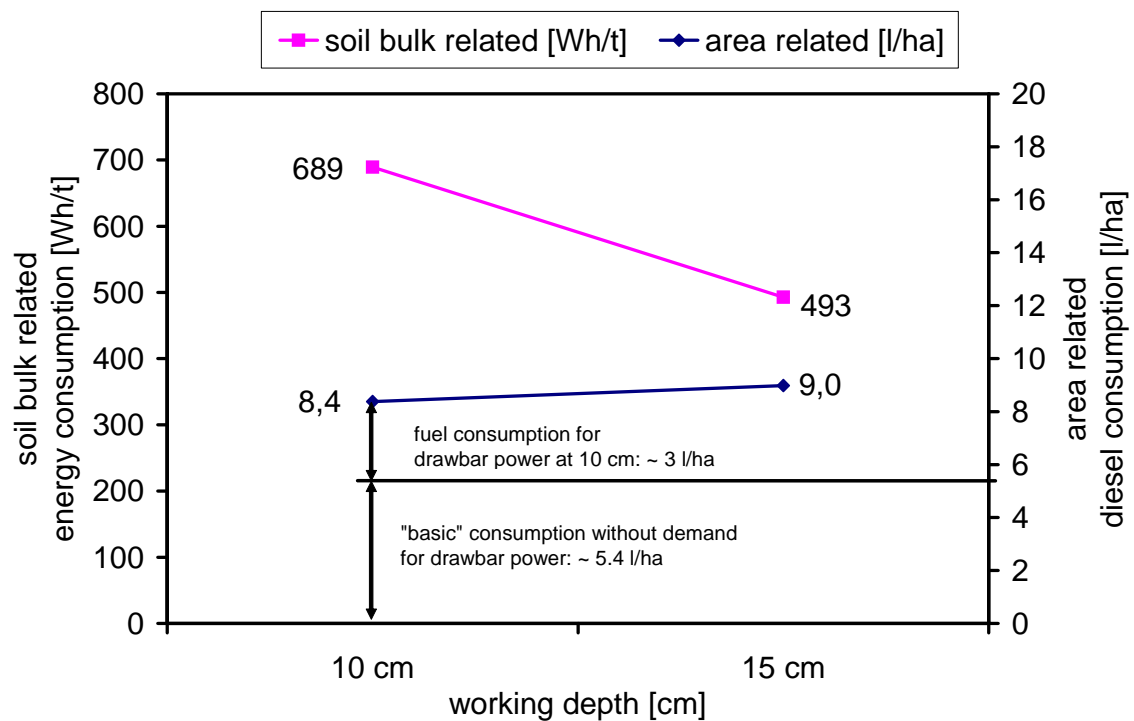


Figure 4: Soil bulk related energy consumption and area related diesel consumption depending on working depth during cultivating with a heavy cultivator (4-wheel drive).

4 Conclusions

The slip in soil tillage is an important factor for analysis of fuel consumption. The improvement of the transmission of the drawbar power to soil could be reached by using 4-wheel drive. The traction efficiency could be improved for a 2-wheel driven tractors with an optimal position of the virtual drawing point (adjusted via the upper link). A reduction of ploughing depth reduces the slip, hourly and area related fuel consumption. In contrast the energy consumption per moved soil bulk increases. It seems that a heavy cultivator caused a lower energy input per tonne moved soil bulk than a plough. Further trials with the same working depth for plough and heavy cultivator should clear this not confirmed result. The parameter “energy input per tonne moved soil bulk” expresses the crushing effect of soil matter (mean diameter of aggregates). In terms of minimizing of energy input in soil during soil tillage, further investigations with different tillage machines will be carried out.

5 References

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