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Mulcher energy intensity measurement in dependence on performance

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Abstract. Conventional impact grass cutting and chopping is energy intensive and therefore it is important to reduce energy demands of such a device. In the paper the energy demands of three-rotor mulcher with vertical axis of rotation was measured and analyzed in dependence on the mass performance of the mulcher. Different mass performance was achieved by different ground speed and yield of the grass cover. The measurement was performed on clover-grass meadow hay, from which the samples were taken and analyzed in order to determine the yield and moisture content of the vegetation. The results showed relatively high energy demands of the mulcher. In dependence on the mass performance of the mulcher it is necessary to deliver in average 10.4–22.6 kW m^{-1} of the width of the machine. Specific energy consumption varied in average from 3.35 to 6.34 kWh t^{-1} of the processed material and unit fuel consumption varied in average from 2.56 to 0.94 kg t^{-1}.

Key words: mulcher, energy consumption, grass cutting, meadow hay.

INTRODUCTION

The power requirement of the rotary mower and the mulching machine is usually 2 to 4 times greater than in case of the finger mower with the same width range. Concrete values of the required power per one meter width cut differ in various scientific sources, e.g. the power requirement 5 kW m^{-1} and the required power requirement for the mower with the conditioner 8 kW m^{-1} (ASABE D497.7., 2011), the power requirement 11 to 16 kW m^{-1} on the mower at speed 15 km h^{-1} (Srivastava et al., 2006), the power requirement 10 to 12 kW m^{-1} with a worn out blade (Tuck et al., 1991), the power requirement for mower conditioners 3.5 to 6.5 Kw m^{-1} and the power requirement for mowing without the conditioner is 5 kW m^{-1} (McRandal & McNulty, 1978b). Other scientific sources state that the average required power for mowing and treatment of grass is 8 kW m^{-1}, with the range 5.6–10.4 kW m^{-1} (Srivastava et al., 2006) and when the patency is 120 t h^{-1}, the energy intensity of the rotary mower is approximately 6.67 kW m^{-1} and when sharp knives are used, the energy intensity is 5.67 kW m^{-1} (Syrový et al., 2008).

The typical cutting speed of the disc and rotary mowers ranges from 71–84 m s^{-1} (O'Dogherty, 1982). Optimization of the cutting speed, the knife shape, the blade oblique angle and the blade rake angle can significantly reduce the energy consumption and increase the efficiency of mowing and crushing (Hosseini & Shamsi, 2012; Johnson et al., 2012; Kakahy et al., 2014). The power requirement depends not only on the cutting speed, knives, blades wear, the type of the mower and patency, but also on the kind of processed crop (Chen et al., 2004; Igathinathanea et al., 2010; Ghahraei et al., 2011; Johnson et al., 2012; Jasinskas et al., 2013; Kronbergs et al., 2013; Pecenka et al. 2014). The power requirement also depends on the moisture and stems inclination (Igathinathanea et al., 2010; Kakahy et al., 2013).

The identified energy losses in case of rotary mowers are caused by air flow (so called ventilation effect), pulling of the mower, friction in the drive mechanism and friction with the stubble under the knives (McRandal & McNulty, 1978b). The experiments with the mowers with the vertical rotation axis proved that 50% of the input energy is used for the transport of the plants, while only 3% of the input energy is used for cutting the plant stems (McRandal & McNulty, 1978a). The power requirement of the rotary mowers can be calculated according to the relation number 1 (Persson, 1987).

$$P_{mow} = \left(P_{LS} + E_{SC} \cdot v_f\right) \cdot B_f \quad (1)$$

where: P_{mow} – total power requirement (kW); P_{LS} – losses (air, stubble, gear loses) (kW m^{-1}); E_{SC} – power of cut (kJ m^{-2}); v_f – ground speed (m s^{-1}); B_P – range width (m).

The goal was to determine the energy demands of the mulching machine with different patency of the material. Other goal was to evaluate impact of the material patency on the unit fuel consumption. It can be expected that the unit fuel consumption reach values between 7.5–9.5 l ha^{-1} (Syrový et al., 2013).

MATERIALS AND METHODS

The main goal of the measurement was to determine the input power taken from the PTO shaft of the tractor during mulching the clover-grass cover. The measurement was done on selected land, south of the town Žamberk (latitude 50.0565725°N, longitude 16.4375197°E). The working set consisted of the tractor John Deere 7930 and the mulching machine MULCHER MZ6000 (Table 1). The tested mulching machine with the range width 6 m is part of the current production programme of the company BEDNAR FMT, s.r.o.

Table 1. Basic parameters of the mulcher MZ6000

Total weight	kg	3,300
Rotor diameter	m	2
Number of rotors	pcs	3
Number of blades per rotor	pcs	4
Rotations per minute	min^{-1}	1,000
Recomended tractor power	kW	110–150

The torque sensor MANNER Mfi 2500 Nm_2000U/min (accuracy 0.25%) was installed on the PTO shaft of the tractor and the flowmeter AIC VERITAS 4004 (measurement error 1%, 2,000 pulse l^{-1}) was placed into the fuel system of the tractor. The flowmeter served for monitoring of the fuel consumption and determination of the energy intensity of the mulching machine. In order to determine the location of the working set and its speed, the GPS receiver was placed on the roof of the tractor. All sensors were connected with the measuring computer (netbook) by means of the analog digital converter LabJack U6. The netbook was placed to the tractor cab. Data were recorded with the frequency of 2 Hz.

Seven measuring sections were marked out on the chosen land, each approx. 100–180 m long (1–7). These sections were used to perform the measuring rides, using the working speed of 3 km h^{-1}, 6 km h^{-1} and 9 km h^{-1} to cover the range of working ground speed used in praxis. The mass performance of the mulching machine was calculated according to the relation (2).

$$W_t = 0.1 \cdot v_p \cdot B \cdot \omega \qquad (2)$$

where: W_t – mass performance of the mulching machine (t h^{-1}); v_p – working speed (km h^{-1}); B – actual range width of the mulching machine (m); ω – yield per hectare of grassland (t ha^{-1}).

The actual range width of the mulching machine was 5.79 m, the average speed of PTO was 998.1 min^{-1} with standard deviation 11 1 min^{-1}. This corresponds with the cutting speed approx. 105 m s^{-1}.

Altogether three samples of mown vegetation were taken from each test section in order to determine the yield of the grass mater and its moisture. The average moisture was 72.8% with standard deviation 4.5%.

The measured data from the individual measuring sections (01 to 07) were loaded into the programme MS Excel and further processed.

RESULTS AND DISCUSSION

The evaluated results of the measurement within the individual sections are presented in the Table 2 and 3. From the Table 2 it can be seen that values of mean power reaches up to approx. 130 kW. Also it can be seen that at speed of approx. 3 km h^{-1} the unit fuel consumption in l ha^{-1} is up to 71% higher than it was expected. At speed of approx. 6 km h^{-1} the unit fuel consumption in l ha^{-1} is approx. 9% higher than it was expected and at speed of approx. 9 km h^{-1} the unit fuel consumption equals to the expectations.

Fig. 1 shows the performance requirement for one meter of the machine range. It is obvious that this requirement increases with the increasing mass performance of the machine, as it might be expected, when the performance of the mulching machine is greater than 30 t h^{-1} it is taken up to 22.6 kW m^{-1}.

Table 2. Measurement results summary – part 1

Section	Speed kmh^{-1}	Yield $t\ ha^{-1}$	Performance $t\ h^{-1}$	Mean torque Nm	Mean power kW
1	3.4	11.2	22.06	890.3	92.55
2	9.34	6.2	33.52	1,272.05	130.96
3	6.66	9.2	35.46	1,194.79	125.9
4	6.47	6.7	25.12	870.35	89.9
5	6.42	7	26.37	841.7	89.32
6	9.28	5.5	29.56	948.78	98.89
7	3.49	4.7	9.58	576.68	60.8

Table 3. Measurement results summary – part 2

Section	Power requirement	Specific energy consumption	Unit fuel consumption		
	$kW\ m^{-1}$	$kWh\ t^{-1}$	$l\ ha^{-1}$	$kg\ ha^{-1}$	$kg\ t^{-1}$
1	15.99	4.2	16.27	13.5	1.21
2	22.62	3.91	7.94	6.59	1.06
3	21.74	3.55	10.37	8.61	0.94
4	15.53	3.58	10.05	8.34	1.24
5	15.43	3.39	10.33	8.58	1.23
6	17.08	3.35	8.47	7.03	1.28
7	10.39	6.34	14.48	12.02	2.56

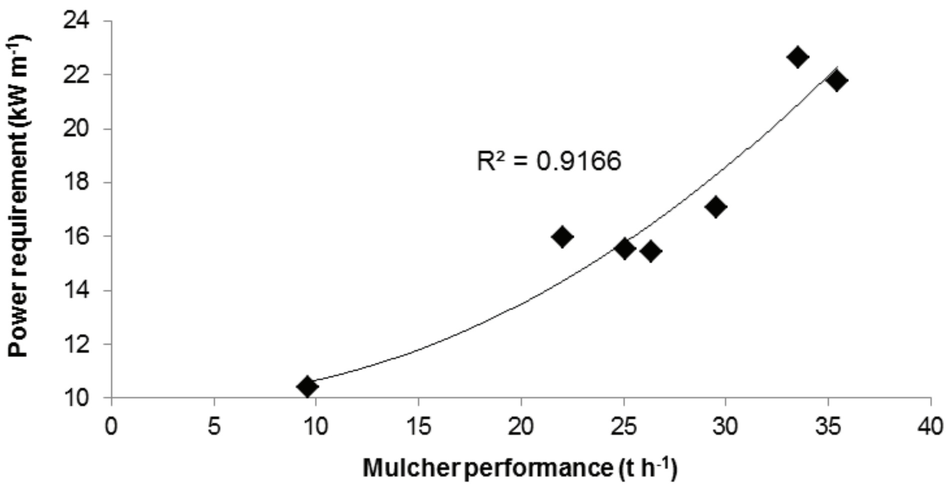

Figure 1. Mulcher power requirement.

Fig. 2 presents the specific energy consumption depending on the performance of the mulching machine. It is obvious that the specific energy consumption decreases along with the increasing mass performance of the mulching machine up to approximately 30 t h^{-1} where the lowest value of the specific energy consumption was reached.

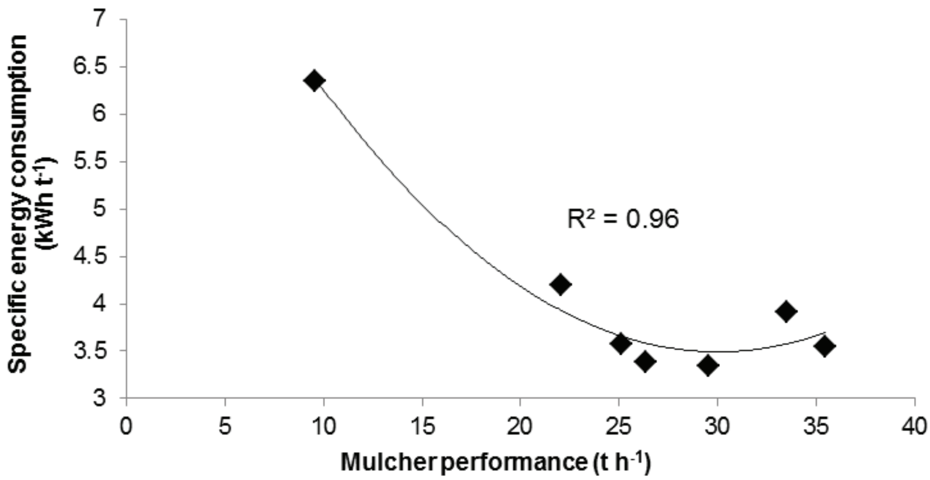

Figure 2. Specific energy consumption of the mulcher.

Fig. 3 shows the unit fuel consumption – kilograms per ton of processed material. As it might be expected the unit fuel consumption decreases along with the increasing mass performance of the mulching machine. However, contrary to the specific energy consumption of the mulching machine (Fig. 2), many other factors interferes in the fuel consumption, e.g. terrain inclination, tractor acceleration etc.

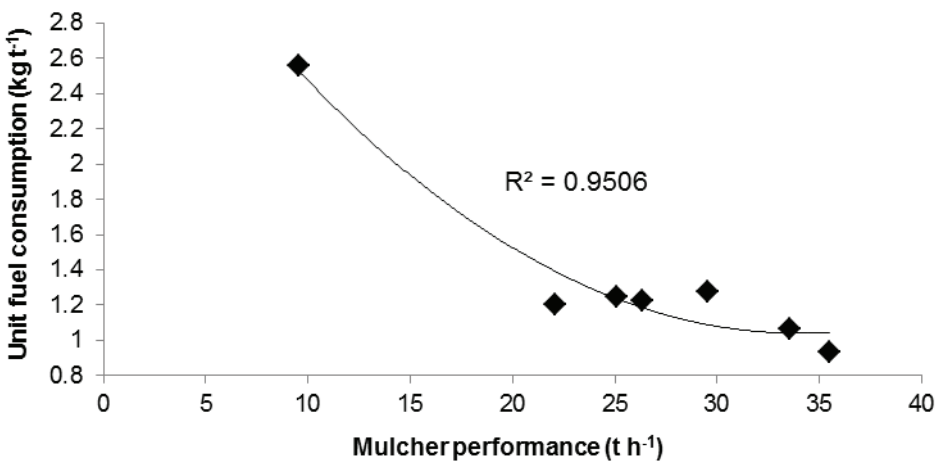

Figure 3. Unit fuel consumption.

CONCLUSIONS

Impact cutting and crushing of the crop material by the rotary mowers requires very high energy consumption. This was confirmed by the measurement, during which the mulching machine needed in average up to 22.6 kW m^{-1} while the patency was 33.5 t h^{-1}, which is much more in comparison with other published scientific work which states from 11 to 16 kW m^{-1} (Srivastava et al., 2006). This could be caused mainly by the ventilation effect, which is required for mulching, and by high cutting speed (105 m s^{-1}). At the speed of 3–6 km h^{-1} the unit fuel consumption in l h^{-1} was also higher than it was expected from the other studies (Syrový et al., 2013). From the point of view of the lowest reached specific energy consumption, the optimal performance of the mulching machine is approximately 30 t h^{-1} and is approximately equal to 3.4 kWh t^{-1}. From the point of view of usage of the fuel energy, the highest reached performance 35.5 t h^{-1} appears to be optimal, because the unit fuel consumption was 0.94 kg t^{-1}. It is possible to reach the required performance by the appropriate working speed of the mulching machine based on the expected yield of the grass matter.

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REFERENCES

ASABE D497.7. 2011. *Agricultural Machinery Management Data*. The American Society of Agricultural and Biological Engineers. St. Joseph.

Ghahraei, O., Ahmad, D., Khalina, A., Suryanto, H. & Othman, J. 2011. Cutting tests of kenaf stems. *Transactions of the ASABE* **54**(1), 51–56.

Hosseini, S.S. & Shamsi, M. 2012. Performance optimization of a rotary mower using Taguchi method. *Agronomy Research* **10**(1), 49–54.

Chen, Y., Gratton, J.L. & Liu, J. 2004. Power Requirements of Hemp Cutting and Conditioning. *Biosystems Engineering* **87**(4), 417–424.

Igathinathane, C., Womac, A.R. & Sokhansanj, S. 2010. Corn stalk orientation effect on mechanical cutting. *Biosystems Engineering* **107**(2), 97–106.

Jasinskas, A., Simonavičiūtė, R., Šarauskis, E., Sakalauskas, A. & Čekanauskas, S. 2013. Assessment of unconventional bioenergy plant chopping, milling and pelleting quality indicators and physical-mechanical properties. *Agronomy Research* **11**(2), 307–318.

Johnson, P.C., Clementson, C.L., Mathanker, S.K., Grift, T.E. & Hansen, A.C. 2012. Cutting energy characteristics of Miscanthus x giganteus stems with varying oblique angle and cutting speed. *Biosystems Engineering* **112**(1), 42–48.

Kakahy, A.N.N., Ahmad, D., Akhir, M.D., Sulaiman, S. & Ishak, A. 2013. Effects of cutting speeds and moisture content on grass chopping (Pulverizing). *Advanced Science Letters* **19**(9), 2533–2535.

Kakahy, A.N.N., Ahmad, D., Akhir, M.D., Sulaiman, S. & Ishak, A. 2014.Effects of knife shapes and cutting speeds of a mower on the power consumption for pulverizing sweet potato vine. *Key Engineering Materials* **594**, 1126–1130.

Kronbergs, A., Kronbergs, E. & Repsa, E. 2013. Evaluation of reed canary grass shredding and compacting properties. *Agronomy research* **11**(1), 61–66.

McRandal, D.M. & McNulty, P.B. 1978a. Impact cutting behaviour of forage crops I. Mathematical models and laboratory tests. *Journal of Agricultural Engineering Research* **23**(3), 313–328.

McRandal, D.M. & McNulty, P.B. 1978b. Impact cutting behaviour of forage crops II. Field tests. *Journal of Agricultural Engineering Research* **23**(3), 329–338.

O'Dogherty, M.J. 1982. A review of research on forage chopping. *Journal of Agricultural Engineering Research*. **27**(4), 267–289.

Pecenka, R. Ehlert, D. & Lenz, H. 2014. Efficient harvest lines for Short Rotation Coppices (SRC) in agriculture and agroforestry. *Agronomy Research* **12**(1), 151–160.

Persson, S. 1987. *Mechanics of cutting plant mater*ial. American Society of Agricultural Engineers (ASAE), St. Joseph, 288pp.

Srivastava, A.K., Goering, C.E. & Rohrbach, R.P. 2006. *Engineering principles of agricultural machines.* American Society of Agricultural Engineers, St Joseph, 588 pp.

Syrový, O., Bauer, F., Gerndtová, I., Holubová, V., Hůla, J., Kovaříček, P., Krouhlík, M., Kumhála, F., Kvíz, Z., Mašek, J., Pastorek, Z., Podpěra, V., Rybka, A., Sedlák, V., Skalický, J. & Šmerda, T 2008. *Úspory energie v technologiích rostlinné výroby (Energy saving in crop production technologies)*. Research Institute of Agricultural Engineering p.r.i. Prague, 101 pp. (in Czech)

Syrový, O., Světlík, M., Pražan, R., Pastorek, Z., Kubín, K. & Gerndtová, I. 2013. *Mobilní energetické prostředky a orientační hodnoty jednotkových spotřeb paliv a energií (Mobile energy devices and the approximate values of unit fuel and energy consumption)*. Research Institute of Agricultural Engineering, p.r.i., Prague, pp. 56 (in Czech)

Tuck, C.R., O'Dogherty, M.J., Baker, D.E. & Gale, G.E. 1991. Field Experiments to Study the Performance of Toothed Disk Mowing Mechanisms. *Journal of Agricultural Engineering Research* **50**, 93–106.