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Measurement of mulcher power input in relation to yield

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Abstract. Mulching is one of relatively energy-demanding operations in plant production. That is why the knowledge of mulcher power input is very interesting and can be used e.g. for mulcher design improvement etc. Field experiments were arranged in order to measure mulcher power input also in relation to yield. The field of about 1.25 ha area was harvested by mulcher MZ6000 produced by BEDNAR FMT Co. This machine has three rotors with vertical axis, working width 6 m and was aggregated with JD 7930 tractor. Power input was measured by torque dynamometer Manner MFI 2500 placed at tractor PTO shaft. Measured data were processed by A/D converter Labjack U 6 and saved. After the harvest, the samples of harvested material from area 6 x 1.65 m were weighted by hands on 102 places in almost regular grid. Average measured mulcher power input was relatively high, 76 kW, with peaks reaching up 145 kW. The yield of harvested material on experimental field was very unbalanced and varied from 0.6 to 13 tonnes per hectare. The amount of measured data allowed the creation of power input and yield maps. By comparing the results from power input and yield measurement it was found that power input significantly depended on the yield. Information of mulcher power input can be used also for harvested material yield mapping.

Key words: mulcher, cutting, power input, yield mapping.

INTRODUCTION

The knowledge of machinery power requirement is important both for machinery development as well as for machinery management. According to Rotz & Muhtar (1992), farm managers use power data to match tractors and implements for efficient and cost effective operations.

Energy demands of different processes of cutting plant materials were studied in past (e.g. O´Dogherty (1982); Persson (1987); Rotz & Muhtar (1992) etc.) while efforts to achieve energy savings during cutting process still remain. New technologies of cutting plant materials were and are still proposed and tested (e.g. Tuck et al. (1991), Zhang et al. (2003), Igathinathane et al. (2007), Maughan et al. (2014) etc.) and energy demands for different plants and different harvesting technologies are still evaluated (e.g. Igathinathane et al. (2010), Wegener & Wegener (2013), Ma et al. (2014), Popp et al. (2015), Lien & Liu, (2015) etc.).

Mulching is among energy intensive crop harvesting operations. It is therefore interesting to deal with mulching energy demands in more details. Processes like mulching were studied in past.

For example, according to O´Dogherty (1982), when using forage harvester, 35% of power only is utilized in chopping and 50% in accelerating the cut material, which in itself is interesting. Other processes than cutting only must be also taken into account.

Persson (1987) published different factors influencing force, energy and power necessary for cutting. In the case of forage harvesters, cutting power increased approximately linearly with wet material feed rate increasing. In the case of rotary mowers, cutting power increased also approximately linearly with forward speed increasing.

Rotz & Muhtar (1992) reported that energy demands of rotary mower are about 5 kW m^{-1} with a range of ± 30% while those of flail mower are in a range of 6 to 15 kW m^{-1} with a typical value of 10 kW m^{-1}.

Taking into account those facts it was decided to measure mulcher power input on tractor PTO shaft in order to better understand its distribution during real harvest. The main aim of this article therefore was to assess mulcher power input distribution during infield tests and to find the influence of different factors on mulcher power needs. This knowledge may be useful for mulcher design improvement.

MATERIALS AND METHODS

The mulcher equipped with three rotors with vertical axis of rotation, type MZ6000, produced by BEDNAR FMT Co. was used for infield tests. The diameter of each rotor was 2 m while 4 knifes are located on each rotor. Therefore, working width of the machine was 6 m and during the measurements it was equipped with John Deere 7930 tractor. Engine power of this tractor was 179 kW. The field of app. 1.25 ha area was harvested during our experiments. Grasslands of different species were grown in our experimental field. Dominating species were *Poaceae (Poa pratense, Phleum pratense, Festuca rubra, Lolium perenne)* in the growth stage from stem elongation to the end of flowering. Important specie was also *Rumex Crispus* after the beginning of flowering.

The measurements of no-load power input were carried out by 23 July 2014 and next day, 24 July 2014, infield measurements were done. Stationary measurements of no-load power were arranged on flat concrete surface. Working height (stubble length) of the machine was set up to usual value of 50 mm. Measurements were done for the range from 500 to 1,000 rpm of PTO shaft (52–105 m s^{-1} knifes peripheral speed).

Mulcher power input was measured by torque dynamometer, type Manner MFI 2500, which was placed at tractor PTO shaft. Torque and shaft rotational speed was measured. Measured data were processed by Labjack U 6 A/D converter. Data were saved every second together with positioning signal from DGPS signal receiver Qstarz BT-Q1000X with positioning precision ± 0.1 to 0.3 m horizontally and ± 0.2 to 0.6 m vertically.

For infield measurements, mulcher stubble length was set to 50 mm (the same as for stationary measurements). It was decided to use forward speed of the mulcher as similar as possible with normal working conditions.

Aerial photos of harvested field were taken from a height of 130 m before and after its harvest using Asctec Falcon 8 drona.

After the harvest, the yield on about one half of the field was determined. 102 samples of harvested material were manually collected and weighted from the areas of 6 x 1.65 m in almost regular grid (see Fig. 2 right).

Data obtained from both measurements were then used for calculation and charting. MS Excel 2010 software was used for calculations and statistical analysis, ArcGIS 10.2 software for maps creation.

RESULTS AND DISCUSSION

The results of mulcher no-load power input measurements can be seen in Fig. 1. It is clear from this graph that no-load power input increased exponentially with PTO rpm increasing. Maximum power input reached 29.15 kW for 1,000 PTO rpm (normal mulcher working rpm). It represented power input of 4.86 kW m^{-1} of working width.

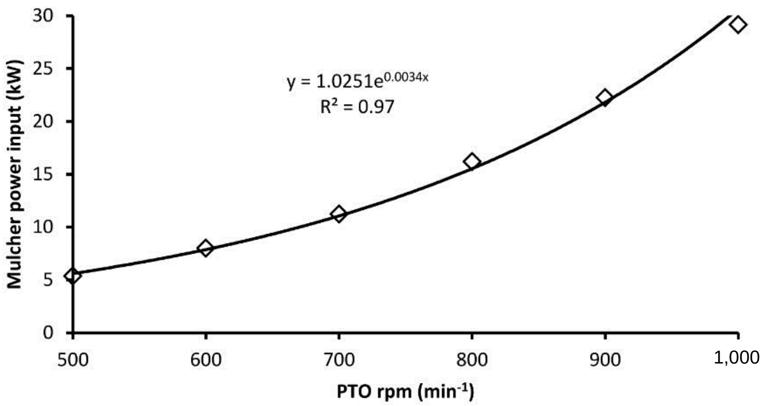

Figure 1. The dependence of mulcher no-load power input on PTO rpm.

The aim of infield measurements was to know power input course during real harvest. That is why forward speed varied in a wide range from 2.98 to 14.32 km h^{-1} with an average of 7.95 km h^{-1}.

Measured mulcher power input also varied in a wide range from 29.86 to 144.25 kW (4.97–24.04 kW m^{-1}) with an average of 79.57 kW. It represents 13.26 kW of average mulcher power input for 1 m of working width. This is in agreement with previously published results for flail mowers power input (6–15 kW m^{-1}; Rotz & Muhtar, 1992) as a comparable machine. Nevertheless, the results obtained were still slightly higher. Authors above reported typical value of 10 kW m^{-1} while our average resulted more than 30% higher. The peaks near to 145 kW were just on the limit of used tractor engine power. It can be caused maybe also by different design of mulching machine. Minimum measured power input corresponded well with the one measured in previous stationary measurement for 1,000 rpm of PTO.

The distribution of measured mulcher power input throughout the field can be seen in the map in Fig. 2 (left).

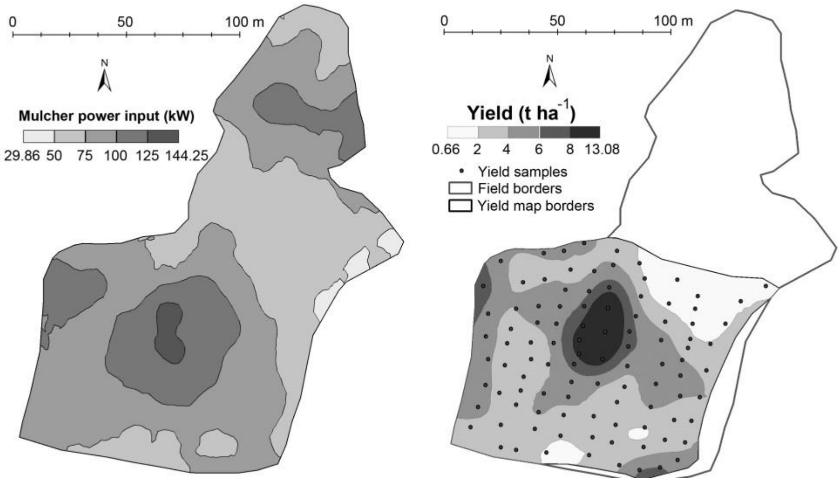

Figure 2. The distribution of mulcher power input measured at tractor PTO shaft during the harvest of experimental field (left) and yield map created in the part of harvested field (right).

In order to study the influence of changes in yield on mulcher power input, a yield map was created from the part of the field where the yield was measured by hands. The yield showed also a wide range of measured values from 0.6 to 13.08 t ha^{-1} with average value of 4.08 t ha^{-1}.

Yield distribution on investigated part of field can be seen in Fig. 2 (right) together with the locations of yield samples collecting areas. Measured mulcher power input can be visually compared with the yield at southern part of the field. It is evident from this comparison that here is a clear dependence of measured power input on harvested grass yield. In the areas with higher grass yield higher conditioner power input was also measured. Taking in mind changing forward speed of harvesting equipment, this result was very interesting. The dependence of these two factors (mulcher power input and yield) was not expected to be so obvious. Persson (1987) reported linear relationship between rotary mower power input and forward speed.

The fact about the mulcher power input dependence on yield was also supported by statistical analysis. 102 points on which hand measurement of grass yield was carried out served as a base for this evaluation. Mulcher power input data from the buffer with a diameter 6 m, the centre of which was each from those 102 points, were averaged and then compared with yield. Summary statistics of the data used for next statistical comparison are provided in Table 1.

Table 1. Summary statistics of the variables used for the statistical evaluation of the dependence of mulcher power input on harvested grass yield

Summary Statistics	Count	Mean	Median	Std. Dev.	Minimum	Maximum	Skewness
Measured grass yield (t ha^{-1})	102	4.11	3.61	2.46	0.66	13.1	1.34
Mulcher power input (kW)	102	90.1	90.44	13.77	68.6	130.5	0.68

Data skewness was in the interval ± 2 in both cases. Common statistical procedures can be used for next data evaluation in this case. Mulcher power input data corresponded well with those displayed in the map (see Fig. 2 left) from investigated part of the field. The dependence of measured mulcher power input on measured yield is expressed graphically in Fig. 3. It follows from this graph that mulcher power input data depended linearly on yield data with sufficient coefficient of determination.

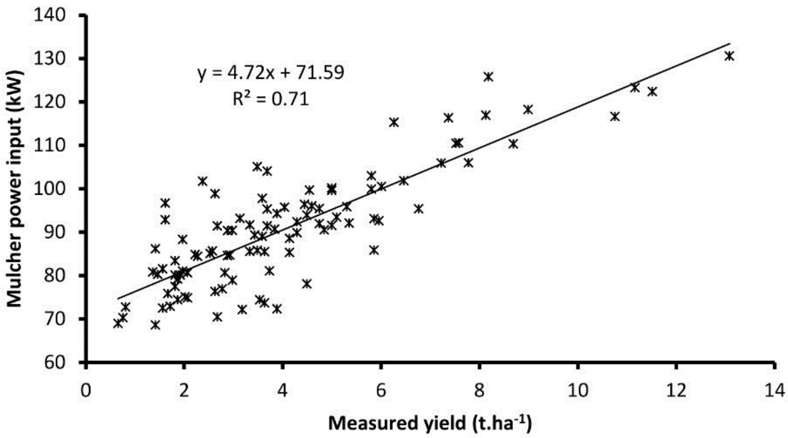

Figure 3. The dependence of measured mulcher power input on measured yield.

Aerial photos of experimental field were taken before (Fig. 4 left) and after (Fig. 4 right) its harvest by mulcher. Fig. 4 (left) well corresponded with yield distribution throughout the field. Darker area represented higher yield can be seen in this figure at the same place as in the yield map. Working paths of harvesting machine are clear from right side of Fig. 4.

Figure 4. Aerial photos of the experimental field before (left) and after its harvest by mulcher.

CONCLUSIONS

Relatively high no-load power input of the mulcher with vertical axis of rotation in comparison with total one was measured. Measured total mulcher power input was also of about 30% higher than the published in literature. In this context, it might be interesting to deal with mulcher design changes or different machine set-up (mainly different PTO rpm) for different harvesting conditions. It could lead to energy savings during mulching operation.

During the harvest, mulcher power input significantly depended on harvested grass yield although travel speed changed significantly. Side effect of mulcher power input measurement can be its use for grasslands yield maps creating. Aerial photos supported results achieved and it can also help with the optimization of working paths.

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