Agronomy Research **14**(2), 540–546, 2016

Estimation of mulching energy intensity

M. Pexa[1], J. Čedík[1,*], F. Kumhála[2] and R. Pražan[3]

[1]Czech University of Life Sciences, Faculty of Engineering, Department for Quality and Dependability of Machines, Kamycka 129, CZ 165 21 Prague 6, Czech Republic
[2]Czech University of Life Sciences, Faculty of Engineering, Department of Agricultural Machines, Kamycka 129, CZ 165 21 Prague 6, Czech Republic
[3]Research Institute of Agricultural Engineering, p.r.i., Drnovská 507, CZ 161 01 Prague 6, Czech Republic
[*]Correspondence: cedikj@tf.czu.cz

Abstract. Mulching is one of the energy-intensive activities in agriculture. The energy is gained from the consumed fuel. Besides the consumed fuel the combustion engine produces harmful and unharmful exhaust gases. The general trend is to reduce the production of harmful constituents of emissions as well as carbone dioxide. This can be achieved by various construction modifications or additional modifications of exhaust gases. It is possible to estimate the energy intensity in advance by several different ways. The paper presents the estimation based on measured complete characteristics of emissions production and the fuel consumption of used combustion engine and on the measured on-board data. The results show that the estimation of fuel consumption and thus also production of carbon dioxide can be relatively successful. The estimation differs quite significantly for other emissions components. During different transition modes of the combustion engine there is a change of emissions production which is hard to describe. The solution could lie in use of other parameters determining the operation mode of the engine in addition to the commonly used speed and torque of the combustion engine.

Key words: Fuel consumption, emissions, operation modelling, combustion engine.

INTRODUCTION

There is a worldwide pressure put on the manufacturers and operators of machines with combustion engine to minimize the fuel consumption and to minimize the production of harmful emissions Aleš et al., 2015. At the same time the engine and medical industry discuss harmful effects of the individual emission components (Hirvonen et al., 2005; Xu & Jiang, 2010; Kvist et al., 2011; Jalava et al., 2012). Harmful effects of the individual emission components are generally known but the problem is to express these harmful effects financially.

Rules and regulations push the manufacturers to produce increasingly sophisticated machines which produce minimum of harmful emissions (Ryu et al., 2014). However, verification of these machines is done only during the homologation measurements (Maass et al., 2009; Lijewski et al., 2013; Cordiner et al., 2014; Liu et al., 2015). Thus the measurement carried out during operation is only indicative and does not achieve sufficient accuracy in order to prove that the combustion engine of the used machine still meets the homologation regulations.

Widely discussed question concerns the evaluation of emissions within the operation which is not easy (Dace & Muizniece, 2015). Measurement of emissions in operation brings number of difficulties such as accuracy of analyzers, speed of response on dynamic change of the measured quantity etc. It would be much easier to monitor the operation mode of the machine and then quantify the actually produced emissions on the basis of complete characteristics of the engine. Within the regular operation test the task would be to specify current complete characteristics of the engine. The vehicle operators would be taxed not according to which machine have they bought but how do they care about it and whether its characteristics are still close to the characteristics determined by the producer or whether the technical condition of the machine has changed so that these characteristics significantly differ from the characteristics determined by the producer. The used type of fuel or biofuel which significantly affects emissions may also be included in the evaluation (Sada et al., 2012; Repele et al., 2013; Hönig et al., 2014; Čedík et al., 2015; Pexa et al., 2015).

The paper presents example of modelling the tractor operation in connection with a mulcher with a vertical axis of rotation. The aim of the paper is to use complete characteristics of the engine and on-board data, achieved during the actual field measurement, to model operation of this set and subsequently compare measured emissions production and fuel consumption of the tractor with the modelled values.

MATERIALS AND METHODS

Measuring and modelling of the operation was done by means of the tractor John Deere 7930 in connection with the triple-rotor mulcher MZ 6000 with a vertical axis of rotation made by Bednar FMT, s.r.o. (Fig. 1). A rotor diameter is 2 meters and the width including overlap of rotors is 5.85 m. John Deer tractor is equipped with the engine supercharged by a turbocharger and also with a common–rail fuel injection system.

Figure 1. Working set of tractor John Deere 7930 and mulcher MZ 6000 during measurement.

Measurement in field conditions was done on a grass field with area of approx. 1.25 ha. The amount of the fuel consumed during the ride of the tractor with the mulcher was measured by means of the flow meter (AIC VERITAS 4004 – measurement error 1%) and also by the on-board diagnostics (on-board diagnostics system monitored by means of the device Texa Navigator TXTs – frequency 4 Hz). The amount of intake air, engine load, engine speed and tractor speed were measured also by means of Texa, the power necessary for the drive of the mulcher was measured by the dynamometer (MANNER Mfi 2500Nm_2000U/min – accuracy 0.25%) and the amount of produced harmful emissions of carbon dioxide (FTIR), carbon monoxide (FTIR), hydrocarbons (FTIR),nitrogen oxides (electrochemical cell) and oxygen (electrochemical cell) was measured by means of the emission analyzer (VMK – frequency 1 Hz, Table 1). Movement of the set was monitored by the GPS sensor (GPS receiver Qstarz BT-Q100X – frequency 5 Hz) and by a drone. All data were synchronized at frequency of 1 Hz.

Table 1. Parameters of the emission analyser VMK

Measured component	Scope	Resolution	Accuracy
CO	0–10% vol.	0.001% vol.	0–0.67%: 0.02% 0.67–10%: 3% from measured value
CO_2	0–16% vol.	0.1% vol.	0–10%: 0.3% 10–16%: 3% from measured value
HC	0–20,000 ppm	1 ppm	10 ppm or 5% from measured value
NO_X	0–5,000 ppm	1 ppm	0–1,000 ppm: 25 ppm 1,000–4,000 ppm: 4% from measured value
O_2	0–22% vol.	0.1% vol.	0–3%: 0.1% 3–21%: 3% from measured value

The yield map was created during measurement on the chosen field. In order to create the yield map, approx. 100 samples of the plant material were taken and weighed and GPS coordinates were also recorded for each sample. The trajectory of the set during measurement and the yield map are presented in the Fig. 2.

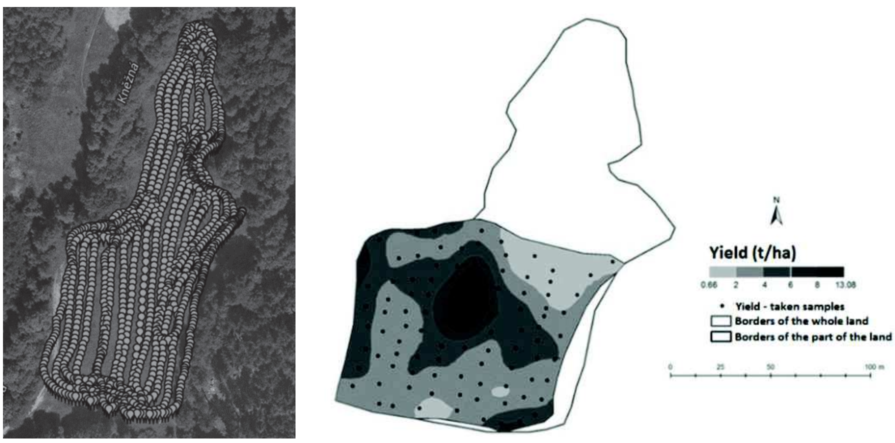

Figure 2. Field measurement: a) measured points, b) yield map.

It was necessary to determine the complete characteristics of the engine to be able to implement modelling. The measurement was carried out in the laboratory by means of the dynamometer (AW NEB 400 – accuracy 2%). The external rotation characteristics was measured. Based on this characteristics the measurement points were determined in order to cover the working range of the engine rotation speed (measured at rotation speed 1,450, 1,600, 1,750, 1,950 and 2,100 at several steps of the engine load up to 100% load – total of 27 points were measured). The fuel consumption and the emission parameters were measured during the measurement. Using functions of MathCad (especially interp and spline) continuous areas were created in coordinates engine speed and torque. The example of continuous area for the fuel consumption is shown in the Fig. 3 and continuous area for the nitrogen oxides is presented in the Fig. 4.

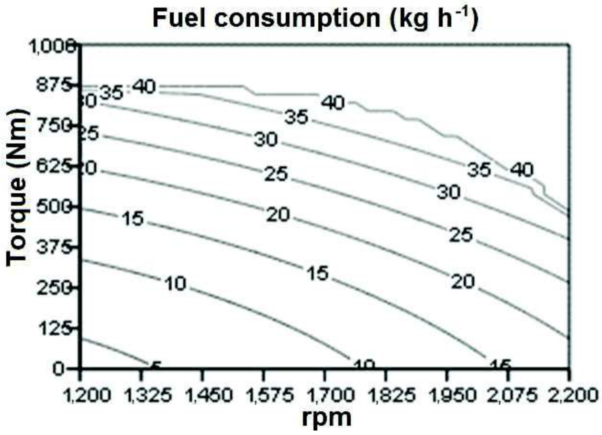

Figure 3. Continuous area of fuel consumption.

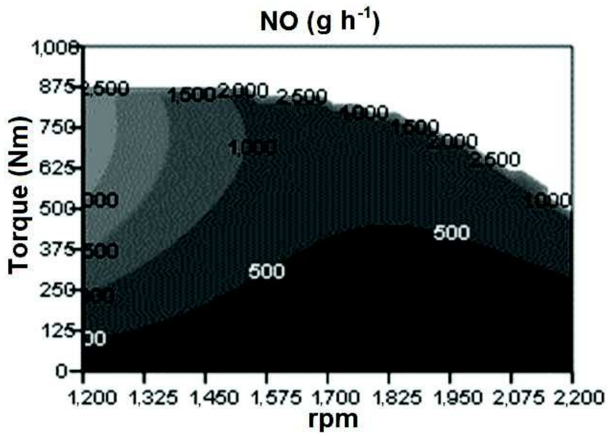

Figure 4. Continuous area of nitrogen oxides.

RESULTS AND DISCUSSION

Altogether 1,417 points were recorded during mulching of the area which is depicted in the Fig. 2, while the driving time was 23.6 minutes. These 1,417 measured points were applied in the model. Production of CO_2, CO, NO, HC and fuel consumption were established for each point using measured complete characteristics of the engine. The total fuel consumption is presented in the Table 2 and the production of the individual emission constituents within the whole ride is presented in the Table 3.

Table 2. Measured and modelled values of fuel consumption for the whole ride

	Measured values l	Model - MathCad l	Deviation %
Fuel consumption	12.86	12.98	0.88

Table 3. Measured and modelled values of produced emissions for the whole ride

	Measured values kg	Model - MathCad kg	Deviation %
CO_2	42.69	56.09	31.40
CO	80.62	121.86	51.15
NO	140.04	226.93	62.05
HC	2.37	0.633	-73.32

The recorded drive points were used to simulate the driving cycle of the tractor and mulcher in the MathCad interface. The resulting values of the whole cycle are presented in Table 2 and 3. It is evident that except the HC production, higher values were reached during modelling of fuel consumption, CO_2, CO and NO_X production than during the real ride (the reason could be the delay of the emission analyser VMK in combination with the low sampling frequency (1 Hz) and very fast change of the engine load during the real ride of the tractor). The best results were reached during modelling of fuel consumption where the average measurement error was 0.88%. The results of CO_2 production are satisfactory but in other cases the measurement error is more than 50%.

Together 14 rides were selected for more detailed analysis of accuracy. These rides were carried out in one direction (elimination of surface inclination and wind direction) and next to each other, in the area where the yield of grass is described. Resulting values of production of individual emissions constituents and the fuel consumption of all 14 rides are evaluated in the Statistica software (Fig. 5).

Table 4. Comparison of measured and modelled values

	Modelled values in comparison with measured value (%)				
	Fuel consumption	CO_2	CO	NO	HC
Mean value	102.66	139.15	172.59	191.15	37.07
Standard deviation	14.51	13.12	31.01	67.15	29.59

The Fig. 5 makes it evident that as in case of the evaluation of the whole ride the model reaches very good values for fuel consumption. The other constituents of emissions acquired from the model are less accurate. The measured values of CO_2 were still acceptable. The accuracy of other emissions constituents is significantly reduced. Resulting values of average and standard deviations are presented in the Fig. 4 and in the Table 4. The results make it evident that the analysis of the tractor set ride based on the on-board values and measured complete characteristics of the engine is not an easy task. It is necessary to introduce correction coefficients for the individual emissions constituents, the coefficients will include dynamics of the engine such as speed change and load change.

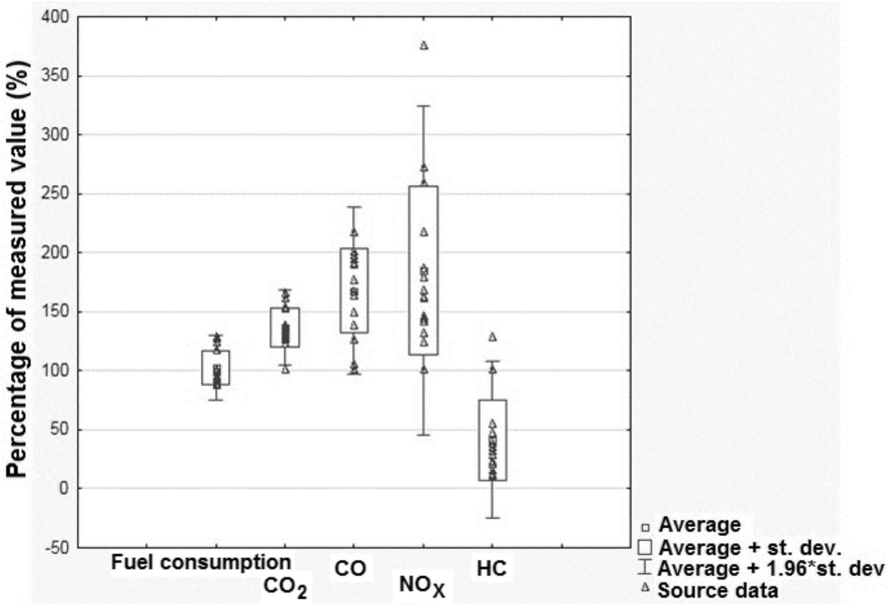

Figure 5. Evaluation of rides – Statistica.

CONCLUSIONS

Modelling the operation of machines and predicting the production of harmful substances of the combustion engine is problematic. The results in Table 2, 3 and 4 show that it is necessary to pay attention to each individual produced emissions constituent. Very good results are reached during modelling of fuel consumption and CO_2. In case of other constituents there are deviations from measured values.

It is possible to make values of produced emissions more accurate when the dynamics of the tractor set ride is taken into consideration. Speed change, course of the speed change and especially load change and speed of load change seem to be appropriate parameters.

Photographic methods for recording of the land are already known. The analysis of the image provides a lot of information which may help to estimate the load of the engine. The tractor set would have to overcome such load during the ride. In connection with complete engine characteristics these maps could be used to predict the fuel consumption and production of harmful substances by the combustion engine.

The aim could be creation of a system of machines evaluation and their impact on the environment. The operation would be taxed on the basis of actual produced amount of harmful substances. The amount of taxes would put a pressure on the operators to renew the vehicle fleet or take care of the fleet in order to produce as little harmful substances as possible.

ACKNOWLEDGEMENTS. The paper was created with the grant support project CULS 2015:31190/1312/3117 – Quality of work and energy intensity of mulcher with vertical axis of rotation using different shapes of cutting tool and within the long-time development project of Research Institute of Agricultural Engineering p.r.i. no. RO0614.

REFERENCES

Aleš, Z., Pavlů, J. & Jurča, V. 2015. Maintenance interval optimization based on fuel consumption data via GPS monitoring. *Agronomy Research* **13**(1), 17–24.

Cordiner, S., Mulone, V., Nobile, M. & Rocco, V. 2014. Impact of biodiesel fuel on engine emissions and Aftertreatment System operation. *Applied Energy*, Article in Press

Čedík, J., Pexa, M., Mařík, J., Hönig, V., Horníčková, Š. & Kubín, K. 2015. Influence of butanol and FAME blends on operational characteristics of compression ignition engine. *Agronomy Research* **13**(2), 541–549.

Dace, E. & Muizniece, I. 2015. Modeling greenhouse gas emissions from the forestry sector – the case of Latvia. *Agronomy Research* **13**(2),464–476.

Hönig, V., Kotek, M. & Mařík, J. 2014. Use of butanol as a fuel for internal combustion engines. *Agronomy Research* **12**(2), 333–340.

Hirvonen, P., Huttunen, H. & Lappi, M. 2005. Estimating the distribution of particle dimensions from electron microscope images. *Proceedings of SPIE - The International Society for Optical Engineering* **5672**, 248–256.

Jalava, P.I., Aakko-Saksa, P., Murtonen, T., Happo, M.S., Markkanen, A., Yli-Pirilä, P., Hakulinen, P., Hillamo, R., Mäki-Paakkanen, J., Salonen, R.O., Jokiniemi, J. & Hirvonen, M.-R. 2012. Toxicological properties of emission particles from heavy duty engines powered by conventional and bio-based diesel fuels and compressed natural gas. *Particle and Fibre Toxicology* **9**, art. no. 37.

Kvist, T., Frohn, U.M. & Jørgensen, L. 2011. Environmental optimisation of natural gas fired engines. *International Gas Research Conference Proceedings* **3**, 1945–1954.

Lijewski, P., Merkisz, J. & Fuc, P. 2013. The analysis of the operating conditions of farm machinery engines in regard to exhaust emissions legislation. *Applied Engineering in Agriculture* **29**(4), 445–452.

Liu, Z.G., Wall, J.C., Ottinger, N.A. & McGuffin, D. 2015. Mitigation of PAH and nitro-PAH emissions from nonroad diesel engines. *Environmental Science and Technology* **49**(6), 3662–3671.

Maass, B., Stobart, R. & Deng, J. 2009. Prediction of NOx emissions of a heavy duty diesel engine with a NLARX model. *SAE Technical Papers.*

Pexa, M., Čedík, J., Mařík, J., Hönig, V., Horníčková, Š. & Kubín, K. 2015. Comparison of the operating characteristics of the internal combustion engine using rapeseed oil methyl ester and hydrogenated oil. *Agronomy Research* **13**(2), 613–620.

Repele, M., Dudko, M., Rusanova, J., Valters, K. & Bazbauers, G. 2013. Environmental aspects of substituting bio-synthetic natural gas for natural gas in the brick industry. *Agronomy Research* **11**(2), 367–372.

Ryu, K., Zacharakis-Jutz, G.E. & Kong, S.-C. 2014. Effects of gaseous ammonia direct injection on performance characteristics of a spark-ignition engine. *Applied Energy* **116**, 206–215.

Sada, O., Mikson, E. & Reppo, B. 2012. Ammonia emission in cowsheds and pigsties during the summer period. *Agronomy Research* **10**(SPEC. ISS. 1), 211–218.

Xu, L. & Jiang, X. 2010. Control of exhaust pollutants from gasoline engine of vehicle. *International Conference on Computer Application and System Modeling, Proceedings* **13**, V13564–V13567.