Acta Technologica Agriculturae 1
Nitra, Slovaca Universitas Agriculturae Nitriae, 2022, pp. 7–12

INFLUENCE OF BIODIESEL ON PERFORMANCE OF MACHINE-TRACTOR UNITS

Volodymyr NADYKTO[1]*, Pavol FINDURA[2], Volodymyr KYURCHEV[1], Oleksander OREL[1]

[1]Dmytro Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine
[2]Slovak University of Agricultural in Nitra, Nitra, Slovak Republic

Currently, liquid biofuels, and especially biodiesel, are increasingly used. In terms of agricultural production, there arises an urgent question whether utilization of biofuels in agricultural tractors is feasible and efficient. Majority of results regarding the biodiesel use comes from bench tests of engines. However, work of any machine-tractor unit under real conditions, except for the steady-state mode of movement, includes acceleration mode after a turn, or after it was forced stop in the field. It has been established that the addition of sunflower methyl ester (SME) into conventional diesel (CD) leads to a decrease in the throttle response of a tractor engine during its field operation. Using 50% CD and 50% SME as fuel mixture, the tillage machine-tractor unit's acceleration time increased by 16.6%. Operating on SME only, the unit's acceleration time reached 50%. The acceleration process of a machine-tractor unit using fuel with addition of SME is non-linear. It consists of two parts: more intensive – with SME content in diesel fuel of up to 50%, and less intensive – with an increase in SME proportion over 50%. When using a mixture of CD with SME in a ratio of 50 : 50, the soil cultivation machine-tractor unit performance decreased by 7.2%, and fuel consumption per tilled area increased by 5.3%.

Keywords: conventional diesel; biodiesel; sunflower methyl ester; throttle response

The concept of using vegetable oil as a fuel, pioneered by Rudolf Diesel in 1895, is experiencing a rebirth. Currently, liquid biofuel is an essential component of many countries' energy balance with insufficient domestic energy resources.

The most common biofuels are bioethanol and biodiesel based on vegetable oils. In terms of agricultural production, there arises an urgent question whether utilization of biofuels in agricultural tractors is feasible and efficient. The answer can have a significant impact on establishing the oilseeds share in the total field crop rotation.

Scientists have already done work in this direction – it was found that, when using ethanol, the operation of agricultural tractor engines at speeds of 1200–2300 rpm is characterized by an increase in specific fuel consumption (de Farias et al., 2017). Mixing CD with ethanol produced following results: in contrast to pure CD, adding 3% of ethanol did not change the engine torque and power (Estrada et al., 2016); by increasing the ethanol content to 15%, the engine power was reduced by 6.3%, while fuel consumption increased by 3.77%.

If butanol is used instead of ethanol, then mixing it with diesel fuel in a 50 : 50 ratio will definitely reduce the fuel efficiency of an agricultural tractor engine (Čedík et al., 2015). The same result is achieved using a mixture of diesel fuel with butanol and sunflower oil (Čedík et al., 2018).

Tractor test of vegetable oil has shown that engine torque can be reduced by up to 15% (Ulusoy et al., 2016). Moreover, utilization of this fuel leads to a significant increase in the smoke level of exhaust gases. Simultaneously, a decrease in their toxicity is achieved by mixing vegetable oil with alcohol in equal proportions (i.e., 50 : 50) (Kardasz and Wróbel, 2014). Approximately the same research results were also obtained by Mohebbi et al. (2012).

Certain researchers argue that vegetable oil-based biodiesel combined with CD can reduce engine fuel consumption by 2–4% (Pexa et al., 2015). Using the example of studies conducted on the Zetor Forterra 8641 tractor, several authors noted the invariance of its engine operating parameters for a fuel mixture consisting of equal parts of hydrogenated vegetable oil and its methyl ester (Aybek et al., 2011).

There has been considered an option of using castor oil as fuel. Concurrently, it was found that even with a content of at least 5% of castor oil, the agricultural tractor engine's specific fuel consumption was increased (de Oliveira et al., 2015). This results from the fact that kinematic and dynamic viscosity of this oil have relatively high values, similarly to olive oil (Hlaváč et al., 2019).

Recently, rapeseed oil methyl ester has been widely used as a fuel. Its physical and mechanical properties in pure form and in a mixture with diesel fuel were substantively described by Kushlyk et al. (2017). Using this mixture in the engine at crankshaft speed of 1500 rpm ensured reduction in NOx by 20% in exhaust gases (Solaimuthu et al., 2015).

Raheman and Phadatare (2004) concluded that Karanja biodiesel (with blend rates of up to 40% with conventional diesel) can be an alternative fuel for diesel engines. Recently, cotton seed oil and its methyl ester, are increasingly used in IC engines and it is expected to be one of the alternative fuels in the future.

Contact address: Volodymyr Nadykto, Dmytro Motornyi Tavria State Agrotechnological University, Melitopol, Ukraine, email: volodymyr.nadykto@tsatu.edu.ua

Al-Iwayzy and Yusaf (2013) observed that the use of biodiesel fuel made of microalgae Chlorella protothecoides in a 25.8 kW engine did not show any decrease in its performance. However, there was a significant reduction in CO and CO_2 emissions.

The use of pure biodiesel in a tractor engine might be considered to be attractive. In this regard, engine bench tests showed that the power and torque of a tractor engine are reduced by 9% and 7%, respectively; furthermore, the specific fuel consumption increases by 13% (Bietresato and Friso, 2014).

The analysis presented follows that the majority of biodiesel utilization results were obtained from bench tests of engines. There are very few studies carried out under the field of tractor operation conditions. These were carried out by Krahla et al. (2002) and Li et al. (2006) and conducted under stationary conditions, repeating the bench tests in principle.

A particular exception to this is the research performed by Plotnikov et al. (2018), who tested the Belarus-922 tractor on two agricultural operation modes in field:

a) ploughing with a PLN-3-35 plough,
b) tillage for sowing with the AKSh-3.6-01 cultivator.

This tractor's engine operated on a mixture of 60% CD and 40% seed oil (SO). Compared to the pure CD, the Belarus-922 tractor engine operation with a plough showed an increase in fuel consumption from 11.86 to 12.54 kg·ha^{-1}, i.e., by 5.7%. Approximately the same result (5.4%) was obtained for operation of this tractor with a cultivator. Emissions of NOx from both units increased by 8–9%. Considering the CO emissions, when working with plough, these practically did not change. When working with cultivator, they decreased by almost 25%.

It should be noted that the studies of units based on the Belarus-922 tractor were carried out in the steady motion mode. At the same time, the real work of any machine-tractor unit includes the acceleration mode after turning. Sometimes, this mode takes place after a forced stop of the machine in field. But it is practically unknown how this mode will behave with the agricultural tractor's engine operating on biodiesel.

In regard to this issue, the purpose of this paper is to determine the degree of biodiesel influence on the engine throttle response during acceleration of machine-tractor unit, as well as on its performance. Firstly, this concerns its work productivity and specific fuel consumption.

Material and methods

Two machine-tractor units were examined under real field conditions. The first consisted of an HTZ-170 tractor (Kharkiv, Ukraine) and a PLN-5-35 five-furrow plough (Fig. 1); the second included the same tractor and a KRNU-8.4 cultivator (Fig. 2).

The tractor weighing 8200 kg was equipped with a 132.3 kW BF6M1013E (DEUTZ) engine. The main plough and cultivator technical characteristics are presented in Table 1.

Table 1 Main technical characteristics of the ploughing and cultivation units

Index	Value	
	PLN-5-35	**KRNU-8.4**
Operating mass (kg)	850	1425
Working device (type)	plow bottom	shovel sweep
Number of working devices	5	39
Constructive width (m)	1.75	8.4

Ploughing machine-and-tractor unit

The ploughing unit was used to study the effect biodiesel on tractor engine throttle response during acceleration. During research, the engine consistently operated on:

a) CD;
b) SME;
c) mixtures of CD with SME.

In general, all fuel types and their mixing ratios are presented in Table 2.

Table 2 Fuel types and their mixtures

CD (%)	**100**	**80**	**50**	**40**	**20**	**0**
SME (%)	0	20	50	60	80	100

Qualitative indicators of CD and SME are presented in Table 3.

To determine the engine throttle response, a special tachometer IMD-2M (Kharkiv, Ukraine) was installed to the tractor PTO shank (Fig. 3). It consisted of a gearwheel with 80 teeth and an MK (Modulated Kinetics) hermetic contact (Kyiv, Ukraine); MK characteristics: type – normally open; minimum response time – 0.5 m·s^{-1}; the minimum release time is 0.1 m·s^{-1}.

Fig. 1 Ploughing machine-tractor unit

Fig. 2 Soil cultivation machine-tractor unit

Table 3 Qualitative indicators of CD and SME

Index	CME (SOU 24.14-37-561:2007)	CD (DSTU 4840:2007)
Cetane index	53	45
Kinematic viscosity at 40 °C (mm·m^{-3})	5	3–6
Density at 15°C (kg·m^{-3})	900	860
Sulphur content (%)	0	0.05–0.5
Acid index	0.4 Mg·KOH·g^{-1}	5 Mg·KOH·(100 cm^{3})$^{-1}$

Fig. 3 Tachometer IMD-2M

This tachometer was used to determine the engine minimum idle speed (N_{min}) and its speed at stable operating mode (N_{max}). The engine operating time from N_{min} to N_{max} was taken as an indicator of its throttle response (t):

$$t = f \cdot n \tag{1}$$

where:
f – tachometer signal recording interval (0.031 s); n – number of tachometer pulses during engine operation from N_{min} to N_{max}

The tachometer pulses for each fuel composition were recorded in four replications by a laptop via an Arduino Uno device (China).

The plough was adjusted to a ploughing depth of 25 cm. In all experiments, the unit moved in the same gear. Prior to studies, the moisture and soil bulk density in layer ranging from 0 to 30 cm were determined twice. The number of measurements of these parameters in each replication is at least 30.

The absolute value of soil moisture was measured using SHS-1 sensor (Kharkiv, Ukraine), which was connected to the laptop via Arduino Uno device (Fig. 4). The device operation principle is based on the ability of water molecules to absorb part of the energy of a high-frequency electromagnetic wave. By comparing the amplitudes of incident and reflected waves, the reflection coefficient is calculated, and, on its basis, the moisture content in the soil is determined. The error of measuring this parameter does not exceed ±1%.

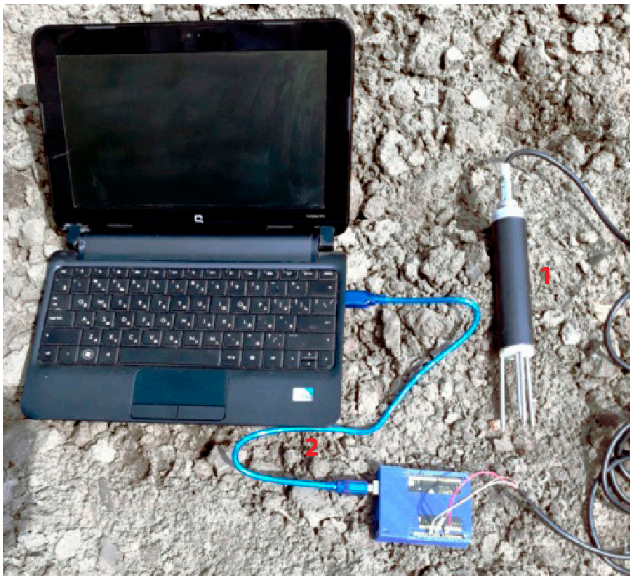

Fig. 4 Soil moisture measuring kit
1 – SHS-1; 2 – Arduino Uno

The soil density was measured using the electronic scales, which made it possible to immediately display the values of this measured parameter in g·cm^{-3} (Nadykto and Kotov, 2015).

Cultivation machine-and-tractor unit

For the first 30 hours (3 days, 10 hours each), the tractor engine of such unit operated on pure CD (option 1); the next 30 hours, it operated on Mixture50 – mixture of CD and SME in a 50 : 50 ratio (option 2).

In both cases, the unit was operated by the same person. In field work, the working width of the unit (B_p), its speed (V_p), the depth of tillage and fuel consumption were recorded. Additionally, there was recorded time spent on:

a) the unit main work (T_1);
b) turns and empty crossings (T_2);
c) technical maintenance of the unit and elimination of failures of its operation (T_3).

Prior to testing the cultivation unit, the moisture content and soil bulk density were determined in the soil layer of 0–15 cm. For these purposes, there were used methods and instruments previously described.

The unit's working width was determined as follows: before the unit's control passage, 100 pegs – with a distance of 1 m from one another – were installed at the distance L (10 m) from the track of cultivator's greatest shovel sweep. As the cultivation machine-tractor unit passed from each

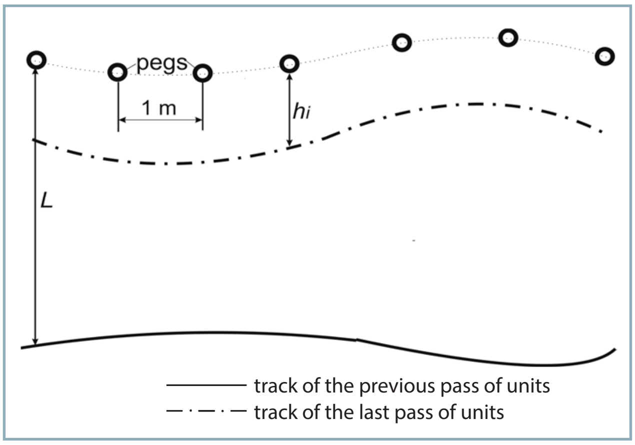

Fig. 5 Measuring scheme of the working width of units

Fig. 6 Instrument for tillage depth measurement

peg to the furrow of newly laid track, the distances (h_i) were measured (Fig. 5).

The working width of machine-tractor unit was calculated as follows:

$$B_p = L - h_i \tag{2}$$

After the passage of a unit, three series of tillage depth measurements were carried out. There were 200 measurements per series, with a step of 0.2 m. The error of the device used (Fig. 6) was ±0.5 cm.

The tractor-machine unit's working speed (V_a) was calculated as follows:

$$V_a = \frac{S}{t_a} \tag{3}$$

where:
S – test site length (S = 250 m); t_a – time necessary for the unit to pass the test site (s)

For the purposes of measurement of time t_a, FS-8200 electronic stopwatch (China) was used.

The unit performance (W_u, ha·h^{-1}) was obtained by:

$$W_u = 0.36 \cdot B_p \cdot V_a \cdot \tau \tag{4}$$

where:
τ – efficiency factor of using unit operating time. It was calculated as follows:

$$\tau = \frac{T_1}{T_1 + T_2 + T_3} \tag{5}$$

The fuel consumption per tilled area (G_f) was obtained by:

$$G_f = \frac{G_o}{W_u} \tag{6}$$

where:
G_o – unit's fuel consumption for 1 hour of operation (kg·h^{-1})

The unit's fuel consumption (G_o) was recorded using DFM 1000 CK TA flow meter (Technoton, Belarus) with a measurement error of not more than 0.5%.

Results and discussion

Ploughing unit acceleration dynamics

The investigated unit operated at the soil moisture content of 20.4%. The average value of the soil bulk density in the 0–30 cm layer was 1.24 g·cm^{-3}.

The experimental data analysis indicate that the unit showed the minimum acceleration time (4.8 s) when the tractor engine operated on pure CD (Fig. 7, curve 1). When operating on SME, the acceleration time increased 1.5 times and amounted to 7.2 s (Fig. 7, curve 3). The unit's acceleration time with engine operating on the Mixture50 was 5.6 s (Fig. 7, curve 2). This is almost 16.6% more than when the tractor engine operated on pure CD, but 22.2% less than when operating on SME.

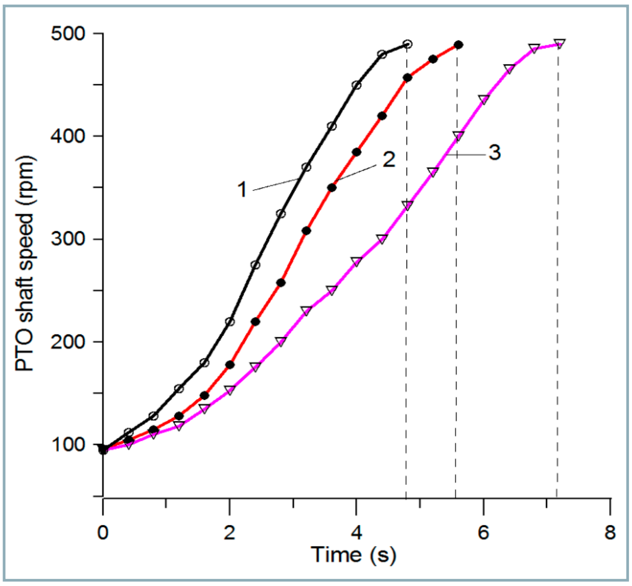

Fig. 7 Acceleration dynamics of ploughing unit with engine operating on different fuel types
1 – CD; 2 – Mixture50; 3 – SME

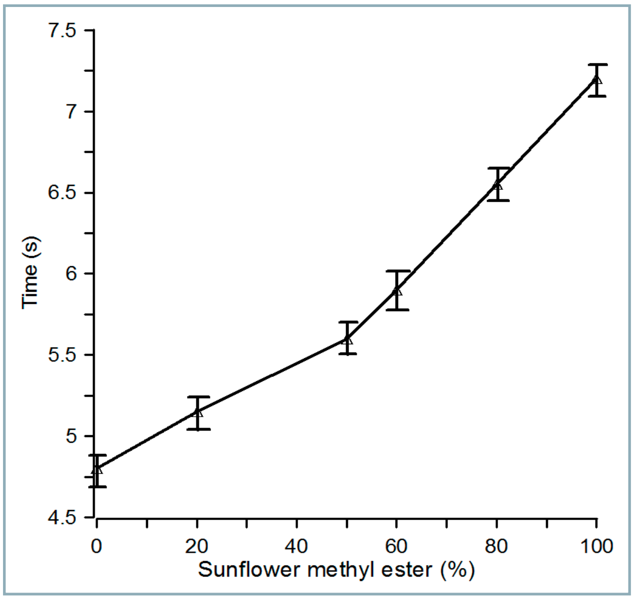

Fig. 8 Influence of CD and SME on the acceleration time of ploughing unit

This can be a result of the fact that the unit acceleration intensity depends on the engine power and the magnitude of its torque. As proven by the bench studies (Estrada et al., 2016; Ulusoy et al., 2016), the latter decreases with an increase in the fuel biological component share. In the case presented, adding SME to CD also led to a certain reduction in engine power and torque. As a result, the acceleration time of the ploughing unit increased.

The ploughing unit's acceleration curves when the engine operated on mixtures of SME and CD in ratios20 : 80, 40 : 60, and 80 : 20 fall into the interval between curves 1 and 3. For a better perception of information, these curves are not shown in Fig. 7.

Analysing the Fig. 7, it is obvious that the curve 2 is closer to curve 1. This fact allows to make the assumption that the acceleration rate (i.e., throttle response) of ploughing unit when the engine is operating on fuel with SME added up to 50% is higher (steeper) in contrast to engine operating on fuel with more than 50% SME content.

To test this assumption, the influence process of all the fuels used and their mixing ratios (Table 2) on the acceleration time of ploughing unit will be considered separately (Fig. 8).

The analysis showed that two parts characterize the ploughing unit acceleration process with the SME content in fuel ranging from 0 to 100%. The first of them represents the unit acceleration process with the SME content from 0 to 50%, and the second from 50 to 100%. Simultaneously, it is evident that with the SME content up to 50%, the increase in acceleration time occurred at a lower intensity than with the SME content higher than 50%.

This result allows conclusion that the influence of SME inclusion in the engine fuel on the unit acceleration time (i.e., throttle response) is non-linear as a whole. Moreover, in the second section of this part, the engine acceleration decreases more intensively than in the first. It follows that to reduce the time acceleration loss, the SME content in the mixture with CD should not exceed 50%.

Cultivation unit test results

The cultivation unit was studied at a soil moisture content of 21.4%. The average value of soil bulk density in the 0–15 cm layer was 1.23 g·cm^{-3}.

Ultimately, the unit of option 1 treated 170 hectares. The area treated by the unit of option 2 was 160 hectares.

The unit working width in both variants of its use was practically the same. The obtained difference in these values – 0.08 m – (Table 4) at a statistical significant level of 0.05 is statistically random, since it is less than LSD_{05} = 0.11 m.

The same can be said for the tillage depth. Considering the unit of option 2, the average value of this parameter was 0.8 cm higher. However, this turned out to be less than LSD_{05} = 1.7 cm.

All in all, in both versions of the unit – as a part of the HTZ-170 tractor and the KRNU-8.4 cultivator – the working width and depth were almost the same. Furthermore, both variants of the cultivation unit used the operating time with approximately the same efficiency. This is evidenced by the obtained practically identical values of the coefficient τ (Table 4). The resulting difference in these coefficients (0.01) is statistically insignificant.

Concurrently, the unit operating speed with engine operating on CD was higher by 6.7% in comparison to the unit with engine operating on Mixture50. As a result, the performance of the second unit was lower by 7.2% compared to the first one (Table 4). Ultimately, the specific fuel consumption of this unit was higher by 5.3%. This practically coincides with the data obtained by Plotnikov et al. (2018). This probably results from the higher efficiency of the CD engine, which was described in detail by Čedík et al. (2018); Estrada et al. (2016), etc.

Table 4 Performance indicators of the cultivation unit with engine operating on different types of fuel

Index	**Fuel**	
	CD	**Mixture50**
Working width (B_p, m)	8.30 ±0.08	8.32 ±0.07
Working speed (V_a, m·s^{-1})	8.0	7.5
Working depth (cm)	11.0 ±1.3	11.8 ±1.1
Coefficient τ	0.86	0.85
Performance (W_u, ha·h^{-1})	5.71	5.30
Fuel consumption per tilled area (G_f, kg·ha^{-1})	3.8	4.0

Conclusion

The addition of SME to CD leads to a decrease in the throttle response of tractor engine during field operation. Therefore, when using a fuel mixture of CD and SME in the ratio of 50 : 50, the acceleration time of the tillage (ploughing) unit increased by 16.6%. When the tractor engine was operating on SME, the increase in this property reached 50%.

The acceleration process of a machine-tractor unit operating on fuel with addition of SME is non-linear and consists of two parts. The first of them reflects a less intensive increase in the unit acceleration time when diesel fuel content is up to 50% of SME. The second is characterized by a sharper increase in this time with an increase in SME content over 50%.

When using a mixture of CD with SME in the 50 : 50 ratio, the soil cultivation unit's performance decreased by 7.2%, and the fuel consumption per tilled area increased by 5.3%. It should be assumed that an increase in the SME content by more than 50% will lead to an even greater decrease in performance and increase in fuel consumption of the units.

Acknowledgements

The paper is supported by the project VEGA 1/0102/21: Reducing chemical loads and degradation of agricultural and forestry soils by selecting appropriate agri-technology with regard to climate change.

References

AL-IWAYZY, S. H. – YUSAF, T. 2013. Chlorella protothecoides microalgae as an alternative fuel for tractor diesel engines. In Energies, vol. 6, no. 2, pp. 766–783.

AYBEK, A. – BAŞER, E. – ARSLAN, S. – ÜÇGÜL, M. 2011. Determination of the effect of biodiesel use on power take-off performance characteristics of an agricultural tractor in a test laboratory. In Turkish Journal of Agriculture and Forestry, vol. 35, pp. 103–113.

BIETRESATO, M. – FRISO, D. 2014. Durability test on an agricultural tractor engine fuelled with pure biodiesel (B100). In Turkish Journal of Agriculture and Forestry, vol. 38, pp. 214–223.

DE OLIVEIRA, M. C. J. – LOPES, A. – DE LIMA, L. P. – NEVES, M. C. T. – YAMAGUTI, P. S. – LIRA, T. A. M. – MORETI, T. C. F. – KOIKE, G. H. A. 2015. Tractor performance in function of storage period and different proportions of biodiesel and diesel. In Australian Journal of Crop Science, vol. 9, no. 10, pp. 909–914.

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. In Agronomy Research, vol. 13, no. 2, pp. 541–549.

ČEDÍK, J. – PEXA, M. – PETERKA, B. – HOLUBEK, M. – MADER, D. – PRAŽAN, R. 2018. Effect of biobutanol-sunflower oil-diesel fuel blends on combustion characteristics of compression ignition engine. In Acta Technologica Agriculturae, vol. 21, no. 4, pp. 130–135.

ESTRADA, J. S. – SCHLOSSER, J. F. – DE FARIAS, M. S. – RODRIGUES, F. A. – MARTINI, A. T. – DOS SANTOS, G. O. 2016. Performance of an agricultural engine using blends of diesel and ethanol. In Ciencia Rural, vol. 46, no. 7, pp. 1200–1205. (In Portugese: Desempenho de um motor agrícola utilizando misturas de óleo diesel e etanol).

DE FARIAS, M. S. – SCHLOSSER, J. F. – RUSSINI, A. – FRANTZ, U. G. – ESTRADA, J. S. 2017. Performance of an agricultural engine using mineral diesel and ethanol fuels. In Ciencia Rural, vol. 47, no. 3, pp. 1–6. (In Portugese: Desempenho de um motor agrícola utili-zando Diesel mineral e etanol).

HLAVÁČ, P. – BOŽIKOVÁ, M. – PETROVIĆ, A. 2019. Selected physical properties assessment of sunflower and olive oils. In Acta Technologica Agriculturae, vol. 22, no. 3, pp. 86–91.

KARDASZ, P. – WRÓBEL, R. 2014. The analysis of the manufacturing and using alternative fuel – A mixture of rapeseed oil and alcohol. In Journal of Ecological Engineering, vol. 15, no. 1, pp. 1–5.

KRAHLA, J. – BÜNGER, J. – SCHRÖDER, O. – MUNACK, A. – KNOTHE, G. 2002. Exhaust emissions and health effects of particulate matter from agricultural tractors operating on rapeseed oil methyl ester. In Journal of the American Oil Chemists' Society, vol. 79, no. 7, pp. 717–724.

KUSHLYK, R. – NAZARENKO, I. – KUSHLYK, R. – NADYKTO, V. 2017. Research into effect of ultrasonic, electromagnetic and mechanical treatment of blended biodiesel fuel on viscosity. In Eastern European Journal of Enterprise Technologies, vol. 2, no. 1(86), pp. 34–41.

LI, Y. X. – MCLAUGHLIN, N. B. – PATTERSON, B. S. – BURTT, S. D. 2006. Fuel efficiency and exhaust emissions for biodiesel blends in an agricultural tractor. In Canadian Biosystems Engineering, vol. 48, pp. 2.15–2.22.

MOHEBBI, A. – KOMARIZADE, M. H. – JAFARMADAR, S. – PASHAI, J. 2012. Use of waste cooking oil biodiesel in a tractor DI diesel engine. In Journal of Food, Agriculture & Environment, vol. 10, no. 2, pp. 1290–1297.

NADYKTO, V. – KOTOV, O. 2015. Method for determining soil bulk density (in Ukrainian: Sposib viznachennya shchilnosti gruntu). UA 97828, G 01N 1/00.

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. In Agronomy Research, vol. 13, no. 2, pp. 613–620.

PLOTNIKOV, S. A. – BUZIKOV, S. V. – TAUSTYKA, V. S. – CHEREMISINOV, P. N. 2018. Determination of operational parameters for Belarus 922 tractor running on mixed fuel. In Mordovia University Bulletin, vol. 28, no. 3, pp. 445–459.

RAHEMAN, H. – PHADATARE, A. 2004. Diesel engine emissions and performance from blends of Karanja methyl ester and diesel. In Biomass and Bioenergy, vol. 27, no. 4, pp. 393–397.

SOLAIMUTHU, C. – GANESAN, V. – SENTHILKUMAR, D. – RAMASAMY, K. K. 2015. Emission reductions studies of a biodiesel engine using EGR and SCR for agriculture operations in developing countries. In Applied Energy, vol. 138, pp. 91–98.

ULUSOY, Y. – ARSLAN, R. – KAPLAN, C. – BOLAT, A. – CEDDEN, H. – KAYA, A. – GŰNÇ, G. 2016. An investigation of engine and fuel system performance in a diesel engine operating on waste cooking oil. In International Journal of Green Energy, vol. 13, no. 1, pp. 40–48.