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Vegetable oil compatible tractors for environmental benefits and regional development

Klaus Thuneke, Johannes Ettl and Peter Emberger, Technologie- und Förderzentrum (TFZ), Schulgasse 18, D-94315 Straubing

Abstract

Pure vegetable oil fuels, used in vegetable oil compatible agricultural machinery, contribute to secure sustainable food supply. Especially rapeseed oil fuel significantly reduces greenhouse gas emissions and thus, lowers the carbon footprint of agricultural products. Harmlessness on climate and environment is guaranteed by the Directive 2009/28/EC in combination with national sustainability ordinances. Additionally, rapeseed oil fuel used for agricultural tractors features benefits such as the increase of regional added value, synergy effects with combined feed production, protection of soil and water and reduced import dependency. However, despite major advantages vegetable oil fuels are barely used in practice, because of technical, economical and sustainability concerns of potential users.
It is the purpose of this work, to show the state of the art of pure rapeseed oil compatible tractors. Based upon 10 years of research with so far 14 tractors of different manufacturers and development stages (exhaust gas stage I, II, IIIA, IIIB and IV) by field tests and test stand trials, results of operational reliability, engine wear, power output, fuel efficiency and exhaust gas emissions are evaluated and compared with diesel fuel operation.
Two vegetable oil operated tractors (exhaust gas stages I and II) have proved full suitability in everyday use for more than 10,000 operating hours. Apart from one defect fuel pump no failures or damages were observed. Examination of injectors and combustion chambers confirmed the good condition of both tractors. Investigation of nine further tractors (exhaust gas stage IIIA) for altogether more than 16,000 hours again showed no considerable failures or damages. Exhaust gas aftertreatment systems enabled a reliable operation with high emission reduction efficiency. Neither performance nor fuel consumption showed any deterioration during the investigated period. Generally, the limited exhaust gas components nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM), determined at a tractor test stand by using the common 8-mode test cycle, remained at the same level. HC and PM emissions with rapeseed oil fuel are mainly lower than with diesel fuel, whereas NO_x emissions are slightly higher. However, with proceeding exhaust gas stages and application of exhaust gas aftertreatment systems differences between fuels become less relevant.
Positive results have encouraged the agricultural machinery industry and authorised workshops to develop tractor prototypes for both diesel and pure vegetable oil fuel operation (“flexible fuel”). Therefore, it is essential to carry on testing of latest technologies with pure vegetable oil fuel. Furthermore, enhanced public relation work, reliable framework conditions and initial incentives can pave the way for a reasonable decarbonisation of agricultural production.

Keywords: tractor, biofuel, vegetable oil, operating behaviour, emission

1 Introduction

Vegetable oils, used as fuel in vegetable oil compatible agricultural machinery, significantly reduce greenhouse gas emissions and thus, lower the carbon footprint of agricultural products in comparison to diesel. Harmlessness on climate and environment is guaranteed by the Directive 2009/28/EC in combination with national sustainability ordinances. Regional processing of vegetable oils from rapeseed, sunflower etc. in decentralised oil mills increases added value of rural areas and contributes to the supply of healthy edible oils, not genetically modified feed, valuable raw materials and high quality renewable energy. Hence the degree of self-sufficiency with above mentioned products within the EU can be increased.
In Germany the predominant vegetable oil used in tractors is rapeseed oil (RSO). Rapeseed oil quality is of crucial importance for a reliable operation of compatible diesel engines. Quality parameters for RSO to be used as fuel, are defined in DIN 51605. In January 2012 the limiting values for the content of calcium, magnesium and phosphorus were strongly reduced. This corresponds to the increased use of exhaust gas aftertreatment systems (e.g. diesel particulate filters and SCR catalysts), which can be affected in efficiency and maintenance by these elements. Apart from rapeseed oil, also other vegetable oils such as sunflower oil or soybean oil can be used as fuel. For these vegetable oils the German pre-standard DIN SPEC 51623 has been developed to specify relevant fuel characteristics.
According to the German Directive 10th BImSchV vegetable oil fuels have to meet the requirements of therein listed standards to be put on the commercial market. Also the energy tax incentives for agricultural use and the crediting for the biofuel quota depend on the compliance with required fuel standards. Therefore, all industrial-scale and decentralised oil mills, regardless of their size, are obligated to offer high-quality vegetable oil fuel in accordance to the fuel standard.
The usage of rapeseed oil fuel in vehicles and machineries requires the technical adaption of engine and periphery (especially fuel system), that is either realized directly by the manufacturer or by a conversion workshop. Different studies show, that vegetable oil compatible tractors can be operated reliably with rapeseed oil fuel (Dieringer & Pickel, 2011; Emberger et al., 2011; Emberger, Thuneke, & Remmele, 2013a; Emberger, Thuneke, & Remmele, 2013b; Hassel et al., 2005; Rathbauer, Krammer, Kriechbaum, Prankl, & Breinesberger, 2008; Thuneke, Gassner, Emberger, & Remmele, 2009). Exhaust gas emissions strongly depend on the operating mode of the engine and the stage of development or exhaust gas stage, respectively.
Exhaust gas stage IIIA tractors from Fendt and Deutz-Fahr with manufacturer release for the use of rapeseed oil fuel were offered from 2008 on. For several years John Deere has been working on tractors fuelled with vegetable oil in demonstration projects (Dieringer & Pickel, 2011). Since 2012 a vegetable oil compatible John Deere tractor with exhaust gas stage IV is being developed together with the University of Kaiserslautern as well as the TFZ, funded by the Fachagentur Nachwachsende Rohstoffe e. V. (FNR). The German agricultural supplier BayWa in Wiesmühl is adapting Fendt tractors with a dual-fuel system, an authorised dealer (Brand Landtechnik, Beilngries) of the Same Deutz-Fahr group is offering vegetable oil compatible Deutz-Fahr tractors and in Austria the company Waldland - Öl- und Bioenergie in Friedersbach is also adapting tractors, such as CNH.
Despite proven ecological and economic advantages, an undifferentiated critical image of biofuels is mainly drawn by the media. Additionally highly subsidized agricultural fossil diesel fuel in many countries inhibits incentives for a broader use of pure vegetable oil fuel in the agricultural sector.
It is the purpose of this work, to show the state of the art of pure rapeseed oil compatible tractors. Based upon several years of research with so far 14 tractors of different manufacturers and development stages (exhaust gas stage I, II, IIIA and IIIB) by field tests and test stand trials, results of operational reliability, power output, fuel efficiency and exhaust gas emissions are evaluated and compared with diesel fuel operation.

2 Materials and methods

Objects of investigation are 14 vegetable oil compatible tractors, 13 of them are being operated at test farms of the Bavarian State Research Center for Agriculture (LfL). During the field test, operational data of the tractors are measured continuously. In addition fuel and engine oil quality are being monitored, operators' experiences recorded and potentially occuring technical malfunctions analysed and corrected.
The tested tractors are listed in Table 1. Most tractors are fully adapted to pure rapeseed oil fuel (single-tank system). Four tractors are equipped with a secondary fuel system (two-tank system), featuring a fuel management system, which provides fuel from either the vegetable oil or diesel tank, depending on the operation mode. During test stand measurement the fuel management system is deactivated for better comparison. This means that during each test cycle, solely one type of test fuel was used. One tractor meets exhaust gas stage I, another tractor stage II, most tractors fulfill exhaust gas stage IIIA, two meet the latest exhaust gas stage IIIB (corresponding to Tier 4i) and one tractor even stage IV (Tier 4 final). Figure 1 shows two tractors of the monitored fleet.

Table 1: Data of monitored tractors.

Tractor type	Year of manufacture	Exhaust gas stage	Engine/ Injection system	Engine power in kW	Fuel tanks	Operating hours (by 2014)
John Deere 6210R (Prototype)	2012	IV	6 cyl. CR[1)]	154	1	950
John Deere 6210R (Prototype)	2012	IIIB	6 cyl. CR[1)]	154	1	700
Fendt Vario 718 SCR	2012	IIIB	6 cyl. CR[1)]	133	2	250
John Deere 6630	2012	IIIA	6 cyl. CR[1)]	103	1	500
John Deere 7830	2010	IIIA	6 cyl. CR[1)]	147	1	1250
New Holland T6080	2010	IIIA	6 cyl. CR[1)]	135	1	no data
Deutz-Fahr Agrotron 650 M	2010	IIIA	6 cyl. CR[1)]	134	2	1400
John Deere 6630	2010	IIIA	6 cyl. CR[1)]	103	1	1500
Fendt Vario[Greentec] 820	2009	IIIA	6 cyl. CR[1)]	152	2	3500
Fendt Vario[Greentec] 820	2009	IIIA	6 cyl. CR[1)]	152	2	2800
John Deere 6930 (Prototype)	2008	IIIA	6 cyl. CR[1)]	114	1	2600
John Deere 6930 (Prototype)	2008	IIIA	6 cyl. CR[1)]	114	1	3000
Deutz-Fahr Agrotron TTV 1160	2005	II	6 cyl. PLN[2)]	119	1	4650
Fendt Farmer Vario 412	2003	I	4 cyl. PLN[2)]	94	1	6100

[1)] CR = Common-rail injection, [2)] PLN = Pump-line-nozzle

Figure 1: Vegetable oil compatible tractors - in front: Fendt 820 greentec (stage IIIA) and in back: John Deere 6210R prototype (stage IIIB).

Emission testing is based on the standard procedure of ISO 8178-1. Differing from type approvals, where engine test stands are used, within this experimental setup measurement is conducted at the entire tractors (Figure 2). The power is measured at the power take-off (PTO) with a dynamometer (EGGERS PT 301 MES). As testing cycle the stationary 8-mode test, which is also known as Non-Road-Steady-Cycle (NRSC), is applied. Within the NRSC the emission results of every single test stage are added up with consideration of specified weighting factors. The emission results over the whole test cycle are calculated in g/kWh$_{PTO}$.
A detailed description of the exhaust gas test stand is given in Thuneke et al. (2009).
Recorded exhaust gas emissions are nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM), which are limited by law and thus referred to as “limited components”. Besides the emission concentrations, the power at the rear power take-off (PTO), torque and fuel consumption are logged continuously.
As reference fuel specified diesel test fuel (CEC RF-06-03) was used. All trials were conducted with cold-pressed rapeseed oil, complying with the national German standard DIN 51605 for rapeseed oil fuel.

Figure 2: Vegetable oil compatible tractor at the test stand of the TFZ.

3 Results and Discussion

3.1 Operating behaviour

All tractors have proven their full suitability in everyday use for altogether some 30,000 operating hours. So far period of observation was longest for the Fendt Farmer Vario 412 with 6,100 and the Deutz-Fahr TTV 1160 with 4,650 hours. Apart from one defect fuel pump severe failures were not recognised at any observed tractor. Minor disfunctions concerned: insufficient pressure in the low pressure fuel system due to pump or valve weakness, problems with automatic switchover from diesel to rapeseed oil operation, exceptional nominal-actual value differences (display of trouble codes by the electronic control unit), which were not considered during software adaption for vegetable oil compatibility. All these problems could be eliminated effectively.
As seen in Figure 3 the analyses of the engine oil demonstrate the necessity of a more frequent engine oil exchange for the vegetable oil compatible tractors with pump-line-nozzle injection, due to the typical accumulation of vegetable oil fuel. However, for all tractors of stage IIIA and beyond with common rail injection the amount of fuel, accumulating in the engine oil is very low. This indicates a proper combustion and results in reduced maintenance, which is comparable with diesel operation. For example fuel accumulation in engine oil for the John Deere tractors was less than 4 % after 500 operating hours.

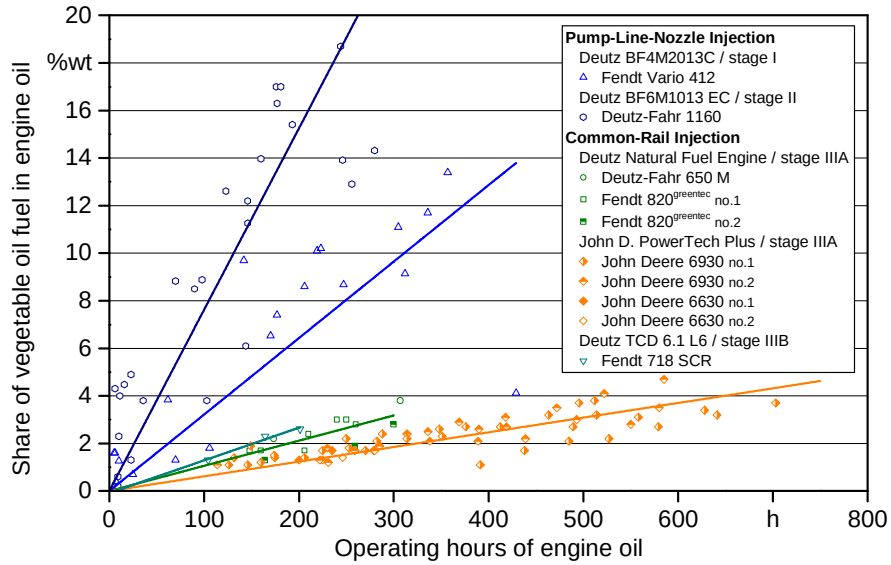

Figure 3: Share of vegetable oil fuel in engine oil over operating hours of engine oil in tractors.

Regarding performance and fuel consumption, none of the tractors showed any significant changes during the investigated period. In accordance with former results, tractors with pump-line-nozzle injection achieved a slightly higher power output with rapeseed oil in comparison to diesel fuel as can be seen in Figure 4 for the Fendt Farmer Vario 412 tractor.

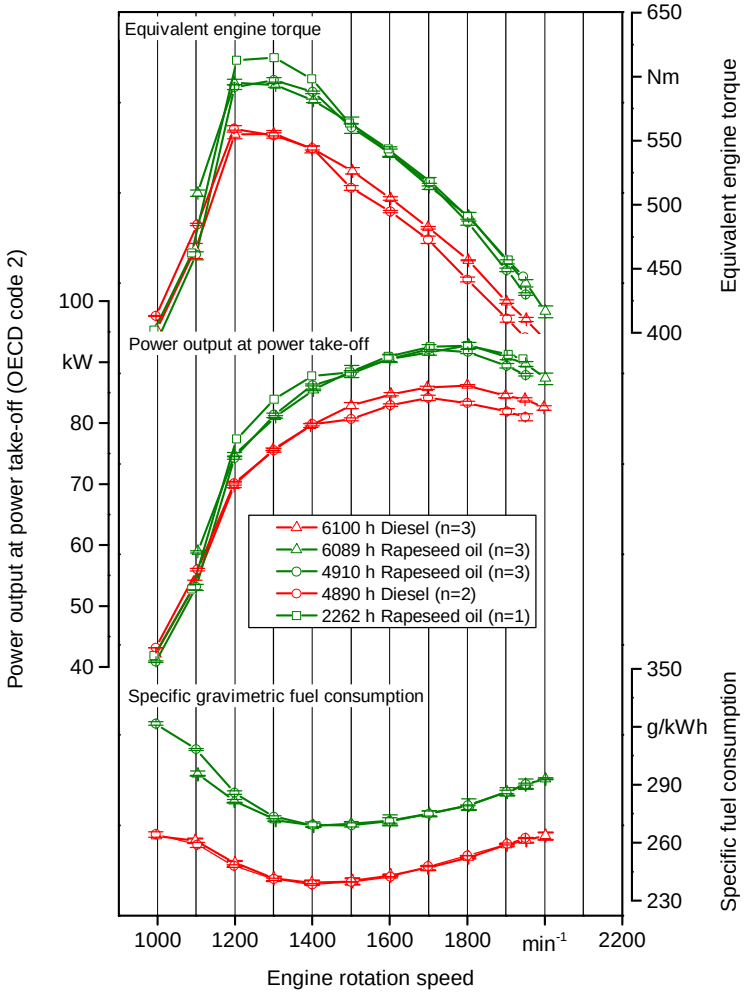

Figure 4: Power, torque and fuel consumption of the Fendt Farmer Vario 412, fuelled with diesel and rapeseed oil.

Tractors of stage IIIA and beyond with common-rail injection revealed a lower power output than with diesel. Reasons therefore are differences in fuel properties (e.g. net calorific value, viscosity, compressibility) between rapeseed oil and diesel and the interaction of fuel properties with type and design of the injection system. In any case, power output adjustment is possible by adapting the engine control unit.
Inspection of the engines confirmed the good condition of the tractors. Figure 5 shows the dismounted pistons, cylinder head areas and cylinder liners of the Fendt Farmer Vario 412. As it can be seen pistons and cylinders were completely free of deposits with exception of harmless reddish residues at one piston (cylinder 4). Besides that, the compression pressure in each of the cylinders was at a constant high value, indicating well sealing piston rings.

Figure 5: Pistons, cylinder head areas and cylinder liners (no. 1 to no. 4 from left to right) of tractor Fendt Farmer Vario 412 (exhaust gas stage I) at engine inspection after 5,000 h.

3.2 Emission behaviour

Overall the exhaust gas components nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM) determined at the tractor test stand remained more or less at the same level during the investigation period.
Figure 6 gives an overview of the results of emission measurements of four tractors with the exhaust gas stages I, II, IIIA and IIIB with rapeseed oil and diesel fuel. The height of the columns corresponds to the arithmetic average of three individual measurements.
There is a significant reduction of the emission level with proceeding exhaust gas stage for nearly all components. Considering the higher values determined at a tractor test stand (by referring them to the work at the power take-off) in comparison to engine related values at engine test stands for type approvals the relevant limiting values are met by all tractors with diesel and rapeseed oil fuel.
Comparing rapeseed oil and diesel operation, slightly higher NO_X, but lower emissions of CO, HC and particulate mass (PM) were observed with rapeseed oil for the tractors with exhaust gas stages I, II and IIIA. Higher NO_X emissions for vegetable oil fuelled engines result from fuel born oxygen and higher combustion temperatures, both factors that stimulate NO_X formation. The tractor with exhaust gas stage IIIB that is equipped with an SCR exhaust gas aftertreatment system for exhaust gas denitrification shows marginally lower NO_X emissions during vegetable oil operation and very low concentrations of CO, HC and PM, which were close to the detection limit.
Overall differences in emission behaviour between vegetable oils and diesel fuel decrease with proceeding exhaust gas stage and emission control measures. The observed emission behaviour of tractors using the 8-mode-test with rapeseed oil and diesel fuel are consistent with former studies such as Rathbauer et al. (2008).

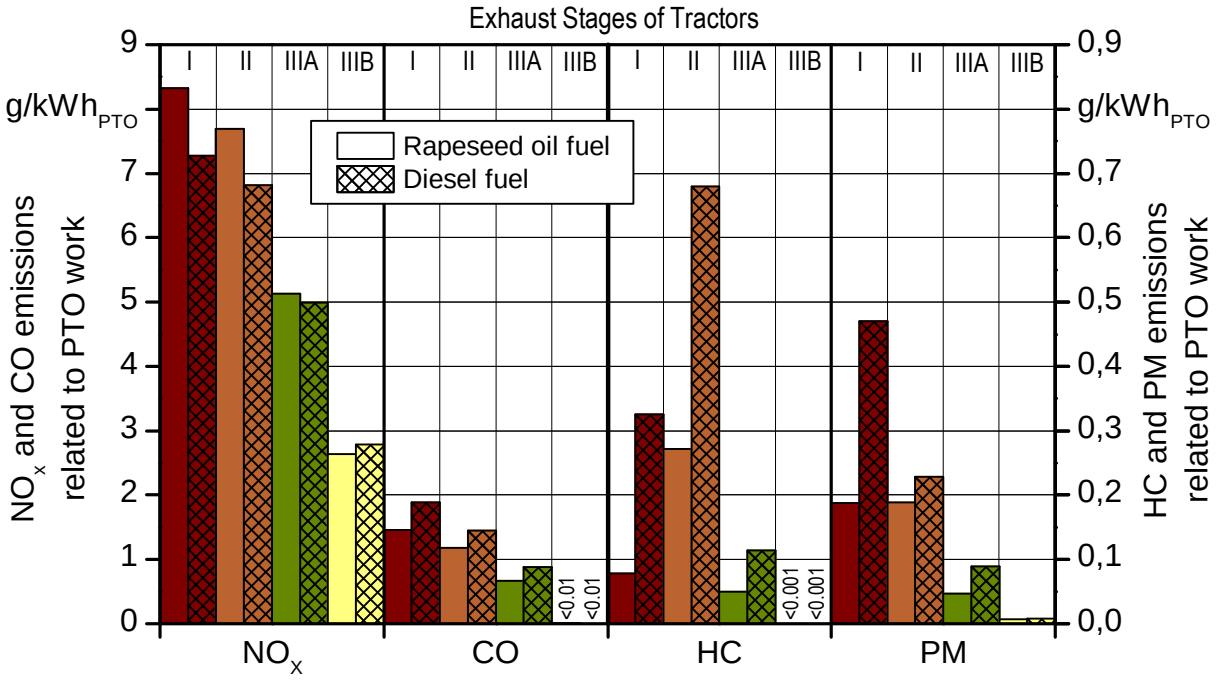

Figure 6: Specific emissions of NO_X, CO, HC and PM (particulate mass) of four tractors (exhaust gas stages I, II, IIIA, IIIB) with rapeseed oil and diesel fuel operation during the stationary 8-mode-test (NRSC) according to modified ISO 8178.

4 Conclusions

During the observation period the 14 vegetable oil fuelled tractors performed a total of about 30,000 operating hours in field operation. In this way about 375,000 l fossil diesel or far more than 700 t CO_{2eq} emissions were saved.

The tractors (exhaust gas stage I, II, IIIA, IIIB and IV) have proven full suitability in everyday use. No considerable failures or damages were observed. Performance and fuel consumption showed no significant changes during the investigated period. The inspection of engines from tractors with up to 5,000 operating hours confirmed the very good condition of the tractors. Exhaust gas aftertreatment systems enabled a reliable operation with high emission reduction efficiency.

Exhaust gas emissions of the tested tractors are in compliance with the requirements of type approvals, when the deviating experimental setup (engine vs. entire tractor test stand) is taken into account. Differences in emission level between vegetable oil and diesel fuel decrease with proceeding exhaust gas stages.

Positive results have encouraged the agricultural machinery industry, authorised dealers and workshops to develop tractor applications for flexible fuel operation with both diesel and pure vegetable oil. Therefore, it is essential to carry on testing performance and long term behaviour of tractors, operated with pure vegetable oil fuel.

For a higher share of vegetable oil fuel used in agricultural machinery public relation work has to be enhanced and framework conditions have to be improved for market stimulation.

5 Acknowledgements

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6 References

DIN SPEC 51623 (2012). Berlin: Beuth-Verlag.

Dieringer, S., & Pickel, P. (2011). One Tank - Multiple Fuels. In: The 2ndVegOil Consortium (Ed.), *Demonstration of 2nd Generation Vegetable Oil Fuels in Advanced Engines. Workpackage 7 Dissemination* (pp. 1–25). Brüssel.

Emberger, P., Landis, M., Krammer, K., Prankl, H., Schaufler, H., Schiess I., & Thuneke, K. (2011). Measurement of emissions of a tractor — round robin test of ART, FJ-BLT and TFZ. *Landtechnik*, *66*(1), 56–59.

Emberger, P., Thuneke, K., & Remmele, E. (2013a). *Langzeiterfahrungen zum Einsatz von Rapsölkraftstoff in Traktoren der Abgasstufe I und II*. (Berichte aus dem TFZ No. 31). Straubing: Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ).

Emberger, P., Thuneke, K., & Remmele, E. (2013b). *Pflanzenöltaugliche Traktoren der Abgasstufe IIIA: Prüfstandsuntersuchungen und Feldeinsatz auf Betrieben der Bayerischen Landesanstalt für Landwirtschaft* (Berichte aus dem TFZ No. 32). Straubing: Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ).

Hassel, E., Prescher, K., Berndt, S., Flügge, E., Golisch, J., Harkner, W., … (2005). *Praxiseinsatz von serienmäßigen neuen rapsöltauglichen Traktoren: Abschlussbericht über die Begleitforschung zum Demonstrationsvorhaben, Aktenzeichen: 00 NR 200, Teil 1*. Rostock: Lehrstuhl für Kolbenmaschinen und Verbrennungsmotoren der Universität Rostock.

ISO 8178-1 (2006). Geneve, Switzerland: International Organization for Standardization (ISO).

Rathbauer, J., Krammer, K., Kriechbaum, T., Prankl, H., & Breinesberger, J. (2008). *Rapsöl als Treibstoffalternative in der Landwirtschaft: BMLFUW-LE. 1.3.2/0037-II/1/2006, Forschungsprojekt 1337, Endbericht*. Wieselburg; St. Pölten: HBLFA Francisco Josephinum; BLT Biomass, Logistics, Technology; AGRAR PLUS GmbH.

Thuneke, K., Gassner, T., Emberger, P., & Remmele, E. (2009). *Untersuchungen zum Einsatz rapsölbetriebener Traktoren beim Lehr-, Versuchs- und Fachzentrum für Ökologischen Landbau und Tierhaltung Kringell*. (Berichte aus dem TFZ No. 17). Straubing: Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ).