NEW PLANT OIL COMPATIBLE TRACTORS – EXPERIENCES AND DEVELOPMENT IN GERMANY

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ABSTRACT: Pure plant oils, used as fuel in compatible tractors reduce greenhouse gas emissions of the agricultural sector and thus, lower CO_2-footprints of agricultural products. Furthermore plant oils can contribute to increase security of supply of long-term moderately priced fuels for the agricultural production. Since 2008, leading manufacturers offer rapeseed oil compatible tractors. However, the operating and emission behaviour of new compatible tractors, fuelled with plant oils is widely unknown. Thus, it is the purpose of a present research project, financed by the Bavarian State Ministry of Food, Agriculture and Forestry to investigate a fleet of - so far - 13 plant oil compatible tractors of different manufacturers in regard to functionality, performance, fuel consumption and exhaust gas emissions in practice field tests and on a test stand. All plant oil fuelled tractors showed very good operational reliability and all in all similar performance, fuel efficiency and exhaust emission behaviour in comparison to diesel operation. However, further research on the long-time behaviour of new tractors with exhaust aftertreatment systems and the upcoming final exhaust stage IV is necessary. For broader market introduction, short-term stimulation of plant oil fuel use in agricultural machinery is necessary.
Keywords: rapeseed oil, vegetable oil, liquid biofuel, alternative fuel vehicle, emissions, operation and maintenance

1 INTRODUCTION

Plant oils, used as fuel in compatible agricultural machinery significantly reduce greenhouse gas emissions and thus, lower the CO_2-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 plant oils from rapeseed, sunflower, soybean, Camelina 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 plant 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, which is used as fuel, were defined in DIN 51605 in the year 2010 [1]. 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 plant oils the German pre-standard DIN SPEC 51623 [2] has been developed to specify relevant fuel characteristics.

According to the German Directive 10. BImSchV plant 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 the fuel standards. Therefore all industrial-scale and decentralised oil mills are - regardless of their size - obligated to offer high-quality standard conform plant oil fuel.

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. Hassel et al. (2005) [3], Rathbauer et al. (2008) [4], Thuneke et al. (2009) [5] and Emberger et al. [6] showed, that vegetable oil compatible tractors can be operated reliably with rapeseed oil fuel. Exhaust gas emissions strongly depend on the operating mode of the engine and the stage of development (exhaust stage).

Exhaust gas stage IIIA tractors of Fendt and Deutz-Fahr with manufacturer release for the use of rapeseed oil fuel were offered since 2008. For several years John Deere has been working on tractors fuelled with vegetable oil in demonstration projects [7] and since 2012 a plant oil 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 is adapting Fendt tractors with a dual fuel system and in Austria the company Waldland is also adapting tractors, such as CNH.

Despite proven ecological and economic advantages, an undifferentiated critical image of biofuels is mainly drawn by media. Additionally highly subsidized agricultural fossil diesel fuel inhibits incentives for a broader use of pure plant 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 13 tractors of different manufacturers and development stages (exhaust 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 APPROACH

Objects of investigation are 13 plant oil compatible tractors, 12 of them are being operated at test farms of the Bavarian State Research Center for Agriculture. The tested tractors are listed in **Table I**. Most tractors are fully adapted to pure rapeseed oil (single-tank system) without using a secondary fuel system for cold starts or idle/low load operation. Four tractors, however, are equipped with a two-tank solution and featuring a fuel

management system, which provides fuel from either, the plant 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. Most tractors fulfill exhaust stage IIIA, two even meet the latest exhaust stage IIIB (corresponding to Tier 4i).

Table I: Data of monitored tractors

Tractor type	Year of manu-facture	Exhaust stage	Engine/ injection	Engine power in kW	Fuel tanks no.
John Deere 6210R	2012	IIIB	6 cyl. CR[1)]	154	1
Fendt 718 Vario	2012	IIIB	6 cyl. CR[1)]	133	2
John Deere 6630	2012	IIIA	6 cyl. CR[1)]	103	1
John Deere 7830	2010	IIIA	6 cyl. CR[1)]	147	1
New Holland T6080	2010	IIIA	6 cyl. CR[1)]	135	1
Deutz-Fahr M 650 Agrotron	2010	IIIA	6 cyl. CR[1)]	134	2
John Deere 6630	2010	IIIA	6 cyl. CR[1)]	103	1
Fendt 820 Vario greentec	2009	IIIA	6 cyl. CR[1)]	152	2
Fendt 820 Vario greentec	2009	IIIA	6 cyl. CR[1)]	152	2
John Deere 6930	2008	IIIA	6 cyl. CR[1)]	114	1
John Deere 6930	2008	IIIA	6 cyl. CR[1)]	114	1
Deutz-Fahr 1160 Agrotron TTV	2005	II	6 cyl. PLN[2)]	119	1
Fendt 412 Vario	2003	I	4 cyl. PLN[2)]	94	1

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

Emission testing is based on the standard procedure of ISO 8178-1 [8]. Differing from type approvals, where engine test stands are used, here the measurement is done at the tractors with mounted engines (**Figure 1**). 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) [5].

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. Tested plant oil fuel was cold-pressed rapeseed oil, complying with the national German standard DIN 51605 for rapeseed oil fuel.

Figure 1: Plant oil compatible tractor at test stand of the Technology and Support Centre (TFZ)

3 RESULTS

3.1 Operation behaviour

The tractors in **Figure 2**, a Fendt Farmer Vario 412 (stage I) and a Deutz-Fahr Agrotron TTV 1160 (stage II) are being operated at the test farm LVFZ Kringell exclusively with rapeseed oil fuel (with exception of the winter months, when diesel is used).

Both tractors proved their full suitability in everyday’s use for some 5800 h (Fendt) and 4400 h (Deutz-Fahr) so far. Apart from one defect fuel feed pump no failures or damages occurred, which can be attributed to the operation with plant oil fuel.

The analyses of the engine oil demonstrate the necessity of a more frequent engine oil exchange (every 250 operating hours) for the plant oil compatible tractors with pump-line-nozzle injection, due to the typical accumulation of plant oil fuel in the engine oil.

Regarding performance, both tractors operating with rapeseed oil fuel showed no significant change during the whole operation period. In accordance with former results a slightly higher power output in comparison to diesel fuel could be achieved with the Fendt tractor (**Figure 3**).

Figure 2: Plant oil compatible tractors: Fendt Farmer Vario 412 and Deutz-Fahr Agrotron TTV 1160

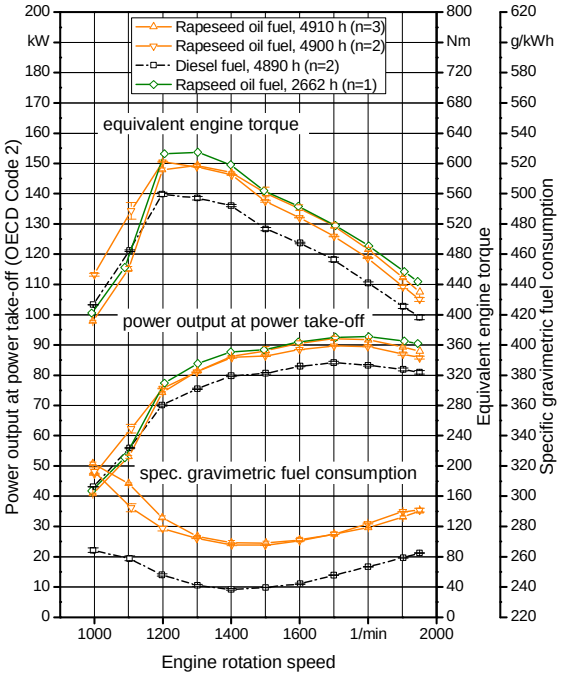

Figure 3: Power output, torque, fuel consumption of a plant oil compatible Fendt Farmer Vario 412 tractor with diesel and rapeseed oil fuel

Inspection of the engines confirmed the good condition of both tractors. **Figure 4** shows the pistons of the Fendt tractor. 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 sealed piston rings.

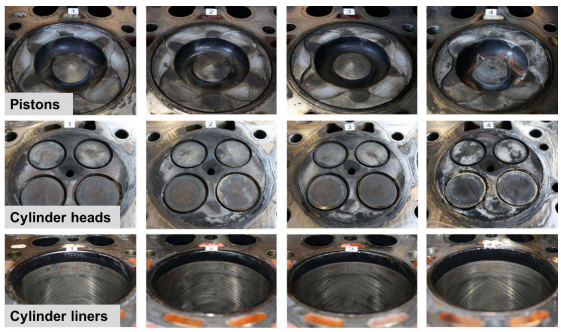

Figure 4: Pistons, cylinder heads and cylinder liners of Fendt Vario 412 (exhaust stage I) at engine inspection after 5000 h

Further investigations on operation behaviour were carried out with three exhaust gas stage IIIA tractors: two plant oil compatible prototypes of John Deere 6930 Premium (**Figure 5**) and one Fendt 820 Vario^{greentec}. The tractors are operated at the test farms LVFZ Kringell, LVFZ Achselschwang and Grub.

Performance and fuel consumption hardly showed any variances during the investigated period. The share of fuel, accumulating in the engine oil is very low for the stage IIIA engines with common-rail injection. This indicates a proper combustion during plant oil operation and results in low maintenance efforts, comparable with diesel operation. Using rapeseed oil fuel all tractors with exhaust gas stage IIIA and common-rail injection system revealed a lower power output than with diesel fuel (in opposite to the Fendt tractor with pump-line-nozzle injection - see above). Reasons therefore are differences in the net calorific value between rapeseed oil fuel and diesel fuel as well as the type, design and modulation of the injection system. Hence, general statements about increasing or decreasing performance by using plant oil fuel cannot be made. In any case, power output adjustment is possible by injection parameter modulation.

Figure 5: Plant oil compatible prototype John Deere 6930 Premium

3.2 Emission behaviour

Overall the exhaust gas components nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM) determined at a tractor test stand remained 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 stages I, II, IIIA and IIIB with rapeseed oil and diesel fuel. The height of the columns corresponds to the arithmetic average of three repetitions.

There is a significant reduction of emission level with proceeding exhaust 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.

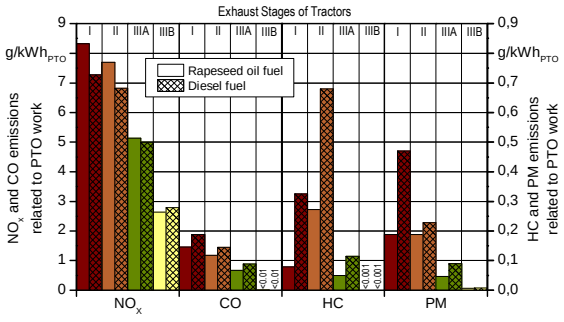

Figure 6: Specific emissions of NO_X, CO, HC and PM (particle mass) of four tractors (exhaust stages I, II, IIIA, IIIB) with rapeseed oil and diesel fuel operation during the stationary 8-mode-test (NRSC) according to modified ISO 8178

Comparing rapeseed oil and diesel operation, little higher NO_X, but lower CO, HC and particle mass (PM) emissions were observed with rapeseed oil for the tractors with exhaust stages I, II and IIIA. Higher NO_X emissions for plant oil fuelled engines result from fuel born oxygen and higher combustion temperatures, both factors that stimulate NO_X-formation. Tractor with exhaust stage IIIB that is equipped with an SCR exhaust aftertreatment system for exhaust denitrification shows only marginally higher NO_X emissions during plant oil operation and very low concentrations of CO, HC and PM, which were close to the detection limit.

Overall differences in emission behaviour between plant oils and diesel fuel decrease with proceeding exhaust 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) [4].

4 CONCLUSIONS

During the observation period the 13 plant oil fuelled tractors performed a total of about 20,000 operating hours in field operation and saved about 250,000 l fossil diesel or nearly 500 t CO_2-equivalents.

The tractors (exhaust gas stage I, II, IIIA and IIIB) have proved full suitability in everyday's use. Apart from one defect fuel pump no considerable failures or damages were observed. The inspection of engines from tractors with up to 5000 operating hours confirmed the very good condition of the tractors. Even exhaust gas aftertreatment systems enabled a reliable operation with lower emissions. Performance and fuel consumption showed no changes during the investigated period.

Exhaust gas emissions of the tested tractors are generally low. Differences between plant oil and diesel fuel almost disappear at low emission levels such as exhaust stage IIIB.

Positive results have encouraged the agricultural machinery industry to develop tractor applications for exhaust gas stage IV for both, diesel and pure plant oil fuel operation. Therefore, it is essential to carry on testing their performance and long term behaviour with pure plant oil fuel.

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

Figure 7: Presentation of rapeseed oil fuel compatible tractors with exhaust gas emission stage IIIA in front of Bavaria's representation in Brussels

5 REFERENCES

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