Emission Behaviour of New Tractors with Different Vegetable Oils

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Summary
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, because they can be produced regionally in decentral oil mills with low input. Since 2008 some of the leading manufacturers of agricultural machinery offer rapeseed oil compatible tractors, mainly for the German and Austrian market. To enlarge raw material base, the usage of other pure plant oils than rapeseed oil is considered. However, the operating and emission behaviour of tractors, fuelled with different plant oils is widely unknown. Thus, it was the purpose of a research project, financed by the Bavarian State Ministry of Food, Agriculture and Forestry to investigate vegetable oil compatible exhaust gas stage IIIA tractors in regard to exhaust gas emissions with diesel fuel, rapeseed oil, sunflower oil and soybean oil.
Both tractors showed significant less hydrocarbon and particle mass emissions during rapeseed oil in comparison to diesel fuel operation. For one tractor with rapeseed oil fuel also lower CO- and equal NO_X- concentrations were ascertained, whereas for the other tractor CO and NO_X were at an higher level. Sunflower oil and soybean oil showed a similar emission behaviour like rapeseed oil and from this point of view they seem a promising option to enlarge the basis for biofuels. However, further research on the long-time behaviour of sunflower oil, soybean oil and further plant oils in tractors is necessary and a fuel quality standard has to be set up like it was done for rapeseed oil.

Key words: exhaust gas, emissions, tractor, vegetable oils, fuel

Introduction

In the last decade, the usage of rapeseed oil as a fuel in tractors gained more and more importance in some European countries, especially in Germany and Austria. Besides environmental benefits, a reduction of fuel costs could be achieved due to tax incentives for biofuels in agricultural machinery.
The 100-tractor-demonstration programme in Germany (Hassel et al. (2005) [2]), the 35-tractor-programme in Austria (Rathbauer et al. (2008) [5]) and a study from Thuneke et al. (2009) [6] showed, that vegetable oil compatible tractors can be operated reliably with rapeseed oil fuel (RSO). Exhaust gas emissions of vegetable oil compatible diesel engines fuelled with RSO strongly depend on the operating mode of the engine. It can be recognized, that in many cases during high-load operation the emissions of carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM) are equal or lower for many vegetable oil compatible diesel engines fuelled with RSO, than for diesel fuelled engines. In contrast, the concentrations of nitrogen oxides (NO_X) are often higher. During low-load or idle operation however, higher CO, HC and PM emissions are often detected, whereas the NO_X-emissions are equal or lower with RSO compared to diesel fuel.
Since 2008 a series produced vegetable oil compatible engine from the Deutz AG with a two-tank system is available. AGCO Deutschland GmbH and Same Deutz-Fahr integrated this engine in tractors, which have been on the market for almost three years by now. A single-tank system was developed by John Deere and is currently under evaluation within the “2nd VegOil” demonstration project [4].
In Germany the predominant vegetable oil used in tractors is rapeseed oil (RSO). The RSO quality is of crucial importance for a reliable operation of vegetable oil compatible diesel engines. Quality

parameters for RSO, which is used as fuel, are defined in DIN 51605 [4]. In September 2010 the standard DIN 51605 replaced the former pre-standard DIN V 51605. The current available series produced vegetable oil compatible tractors feature manufacture approvals solely for RSO complying DIN 51605. Especially for other countries also other vegetable oils, such as sunflower oil (SFO) or soybean oil (SBO) may be of interest to be used as a fuel.
Thus, it is the aim of a present research project to investigate the exhaust gas emissions of stage IIIA tractors fuelled with rapeseed, sunflower and soybean oil in order to evaluate the feasibility of using these plant oils as fuel.

Material and methods

Objects of investigation are two vegetable oil compatible tractors. The technical data of the tested tractors are listed in *Table 1*. One tractor (T1) is entirely adapted to rapeseed oil fuel without using a secondary fuel system for cold starts. The second tractor (T2) is equipped with a two-tank solution featuring a fuel management system, which provides fuel from either the plant oil or diesel tank, depending on the operation mode. During measurement the fuel management system was deactivated. This means that during each test cycle, solely one test fuel was used. When the fuel management system was activated, during the idle test mode of the applied 8-mode-test diesel fuel would be used. Both tractors fulfill exhaust gas stage IIIA and are equipped with an external cooled exhaust gas recirculation (EGR).

Table 1: Technical data of the tested tractors.

Tractor code	**T1**	**T2**
Number of cylinders	6	6
Engine displacement in dm³	6.79	6.06
Rated engine power in kW (for diesel)	114 (with PM[1)] 132)	140
Rated speed in min^{-1}	2100	2100
Exhaust gas stage	IIIA	IIIA
Year of manufacture	2008	2009
Operating hours in h	ca. 625	ca. 350

[1)] PM: Power Management, not activated during measurement

As reference fuel specified diesel test fuel of the quality CEC RF-06-03 was used. Tested plant oil fuels are:

- Two batches of cold-pressed rapeseed oil (RSO1 and RSO2) complying with the national German standard DIN 51605 for rapeseed oil fuel,
- refined and winterized sunflower oil (SFO) and
- refined soybean oil (SBO).

Table 2 shows the properties of the tested plant oils. In comparison to diesel fuel, plant oils feature higher densities and lower heating values. Latter arise from different elemental composition with less carbon and hydrogen content and instead of that the presence of oxygen in the fuel with a content of some 10.9 %. Within the different tested plant oils the elemental composition and heating values are rather similar. Except for the oxidation stability of sunflower oil all tested plant oils meet the requirements of DIN 51605 (which actually only applies for rapeseed oil).

Emission testing is based on the standard procedure of ISO 8178-1 [3]. Differing from type approvals, where engines are operated on engine test stands, the measurements within this research project is done at the whole tractors (with mounted engines). 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. Figure 1 and Table 3 show the single test modes within the engine operating map. A detailed description of the exhaust gas test stand is given in Thuneke et al. (2009) [6].

Table 2: Properties of tested rapeseed oil batches (RSO1 and RSO2), sunflower oil (SFO) and soybean oil (SBO).

Property	Testing method	Unit	RSO1	RSO2	SFO	SBO
Density (15 °C)	DIN EN ISO 12185	kg/m³	920.0	920.2	922.7	922.1
Flash point	DIN EN ISO 2719	°C	237	274	235	282
Kin. Viscosity (40 °C)	DIN EN ISO 3104	mm²/s	34.5	34.5	32.7	32.9
Calorific value	DIN 51900-2	MJ/kg	37.1	37.1	37.1	37.1
Iodine value	DIN EN 14111	g Iodine/100g	111	111	125	121
Sulphur	DIN EN ISO 20884	mg/kg	3.4	<1	1.1	1.7
Total contamination	DIN EN 12662	mg/kg	3	--	13	5
Acid value	DIN EN 14104	mgKOH/g	0.85	1.30	0.05	0.10
Oxidation stability (110°C)	DIN EN 14112	h	6.4	7.0	3.1	6.9
Phosphorous	DIN EN 14107	mg/kg	<0.5	8.2	<0.5	1.3
Mg+Ca content	DIN EN 14538	mg/kg	<0.5	16.3	<0.5	<0.5
Water content	DIN EN ISO 12937	mg/kg	580	442	62	66
Carbon	calculated	mass-%	77.5	77.5	77.5	77.5
Hydrogen	calculated	mass-%	11.6	11.6	11.5	11.6
Oxygen	calculated	mass-%	10.9	10.9	10.9	10.9

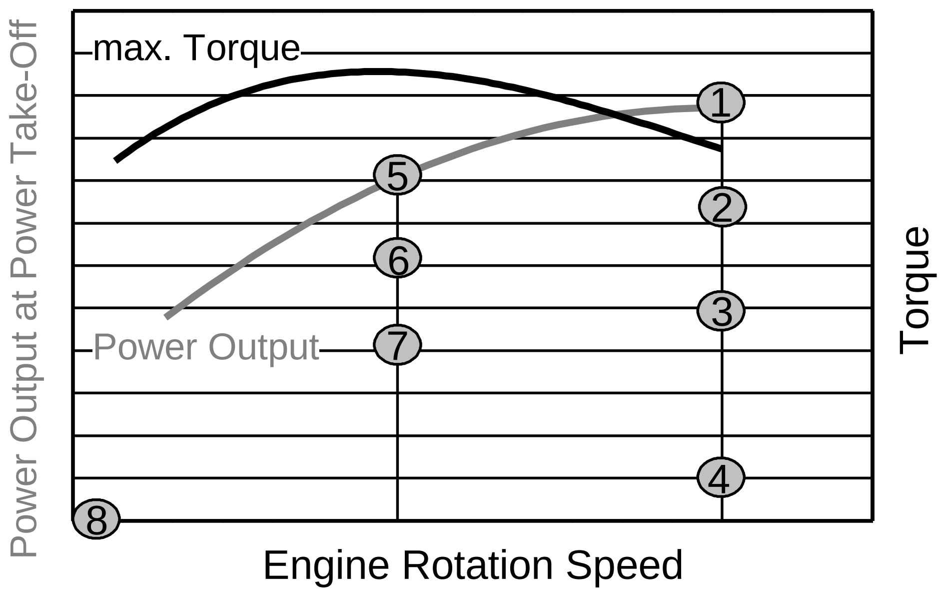

Figure 1: Test modes within the engine operating map according to ISO 8178 for emission testing.

Table 3: Engine speed, load and weighting factors of the eight test modes.

Test mode	Engine speed in min^{-1}		Load in %	Weighting factor
	Tractor T1	Tractor T2		
1	2100 (rated)	2100 (rated)	100	0.15
2	2100 (rated)	2100 (rated)	75	0.15
3	2100 (rated)	2100 (rated)	50	0.15
4	2100 (rated)	2100 (rated)	10	0.10
5	1575 (intermediate)	1450 (intermediate)	100	0.10
6	1575 (intermediate)	1450 (intermediate)	75	0.10
7	1575 (intermediate)	1450 (intermediate)	50	0.10
8	850 (idle)	800 (idle)	0	0.15

Recorded exhaust gas emissions are nitrogen oxides (NO_X), carbon monoxide (CO), hydrocarbons (HC) and particulate mass (PM), which are limited by law and and thus referred to as “limited components”. The test stand analyzers for gaseous components with respective measurement principles are listed in Table 4. Particulate mass is determined by using a partial flow dilution sampler. Besides the emission concentrations, the power at the rear power take-off (PTO), torque and fuel consumption are logged continuously.
Within the 8-mode-test 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}. When the single modes are displayed, the results are shown in parts per million (ppm) on wet basis for the gaseous emission components and in mg/m³ also on wet basis for the particulate mass emissions.

Table 4: Analyzers for nitrogen oxides (NO_X,), carbon monoxide (CO) and hydrocarbons (HC).

Component	Model	Principle
NO_X	Beckmann Industrial 951A	Chemiluminescence detector
CO	Rosemount BINOS 1001	Non-dispersive infrared sensor
HC	J.U.M. FID VE 3-100	Flame ionization detector

Results and Discussion

Emissions for rated 8 test modes

Figure 2 gives an overview of the results of emission measurements of two tractors with different plant oil fuels. The height of the columns corresponds to the arithmetic average and the error bars to the range of variation of three repetitions for the concentrations of the exhaust gas components NO_X, CO, HC and PM during eight test modes in relation to diesel fuel operation (specific diesel emissions are stated as 1.0).
For tractor T1 NO_X-emissions with rapeseed oil, sunflower oil and soybean oil are approximately 20 % higher than with diesel fuel. Higher NO_X-emissions are common for plant oil fuelled engines, due to a higher fuel born oxygen content and higher combustion temperatures, both factors that stimulate NO_X-formation.
Tractor T2 however, shows in sum over the eight test modes the same NO_X-emissions with the tested rapeseed and sunflower oil as with diesel fuel. This might indicate a NO_X-related engine optimisation for plant oil fuel operation.
A similar result by trend can be observed for the CO-emissions. For tractor T1 about 30 % higher concentrations were measured for all tested plant oils compared to diesel fuel. Tractor T2 instead shows up to 40 % lower CO-emissions with rapeseed and sunflower oil than with diesel fuel. HC-emissions are for both tractors some 35 to 45 % lower with plant oils than with diesel fuel. Finally particulate matter emissions are for tractor T1 about 35 % and for tractor T2 over 50 % lower with the plant oils than with diesel.

Overall differences in emission behaviour between the three tested plant oils are not significant for either tractor, when looking at the weighted eight test modes. In terms of the relative emissions between plant oils and diesel fuel the two tractors differ considerably. While tractor T1 is characterized by lower HC- and PM-emissions, but higher NO_X- and CO-emissions during plant oil fuel operation, tractor T2 shows equal NO_X-concentrations for plant oil and diesel fuel usage and distinctive lower CO-, HC- and PM-emissions, when fuelled with plant oils. However, the results, shown in Figure 2 do not give any information about the differences of the absolute height of the emission components between the two tractors.

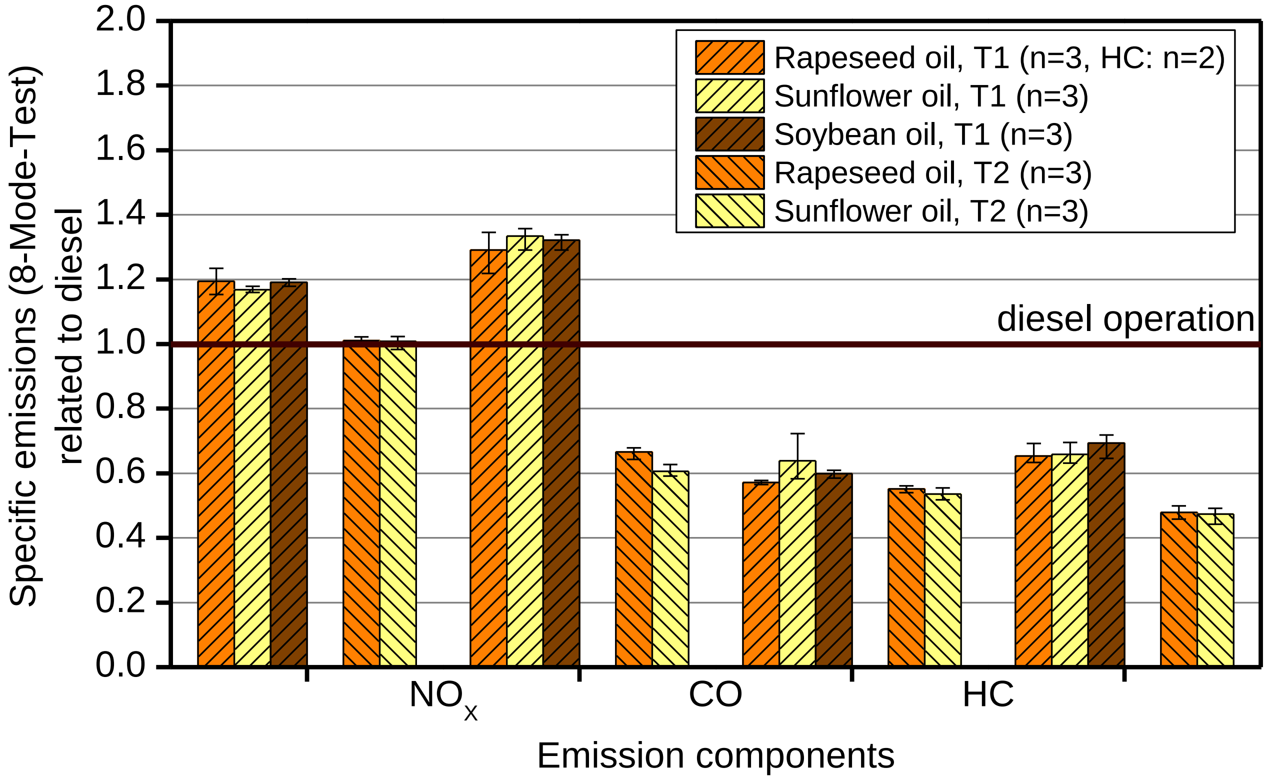

Figure 2: Specific emissions of NO_X, CO, HC and PM of tractor T1 and T2 with different plant oils in relation to diesel operation during the 8-mode-test (NRSC) according to ISO 8178.

Figure 3 and Figure 4 show the NO_X-emission concentrations of tractor T1 and T2 for each of the eight modes within the engine operation map separately. It has to be considered, that the measured maximum power output was higher for diesel fuel than for the plant oils. For tractor T1 the NO_X-emissions are highest during rated engine speed (2100 min^{-1}) and high load modes (100 % and 75 %), they are moderate at intermediate engine speed stages and lowest during low load test modes at rated speed and idle operation. NO_X-emissions are higher for plant oil fuels than for diesel fuel during most test modes apart from idle operation. Soybean oil tends to cause little higher concentrations than rapeseed or sunflower oil, especially during high load modes at rated engine speed.

Tractor T2 has highest concentrations of NO_X during intermediate engine speed. At both intermediate and rated engine speed NO_X-emissions decrease with decreasing load. Plant oil fuel operation leads to a lower absolute value of NO_X than diesel fuel operation. Related to the power, which is higher during diesel fuel operation however differences are not evident. Comparing the tested plant oils emission concentrations tend to be higher with sunflower oil than with rapeseed oil fuel.

As shown in Figure 5 CO-emissions of tractor T1 are very low through all test modes. Remarkably higher concentrations are measured only for idle operation (test mode 8) during plant oil operation. The plant oils do not differ much from each other in emission behaviour.

Tractor T2 has overall also very low CO-emissions (see Figure 6). Plant oil fuels show lower concentrations than diesel fuel during test modes at intermediate engine speed, but higher CO emissions during idle operation at test mode 8. For rapeseed oil and sunflower oil, results are again rather equal.

The HC-emissions of both tractors T1 and T2 are displayed in Figure 7 and Figure 8. They are consistently much lower with plant oil fuels than with diesel fuel. Idle operation however is the only exception, where values with diesel fuel are lower or equal. With tractor T1 sunflower oil tends to show higher emissions than rapeseed and soybean oil, but differences are marginal. For tractor T2 no significant differences can be noticed.

The PM-emissions, shown in Figure 9 and Figure 10 are similar to the HC-emissions for both tractors with clear advantages for plant oils in comparison to diesel fuel except from the idle test mode. Differences between rapeseed oil, sunflower oil and soybean oil are not evident.

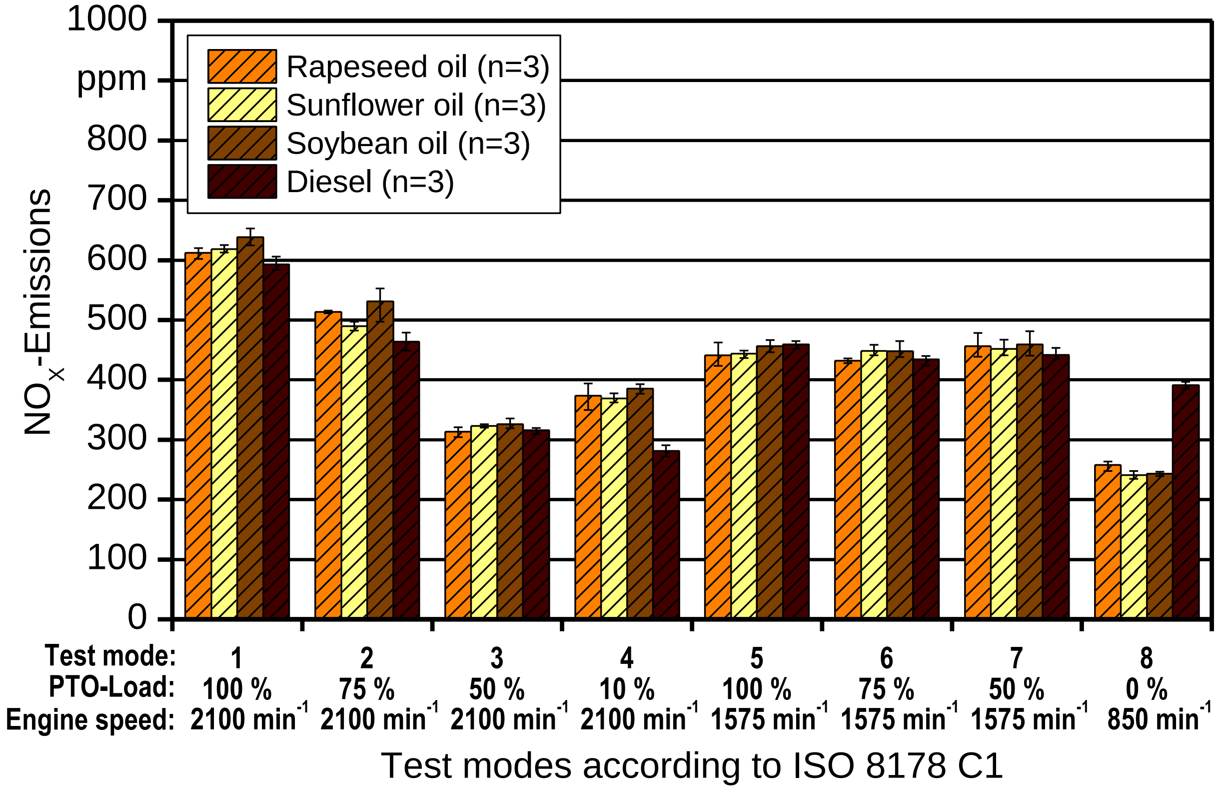

Figure 3: NO_X-emissions of tractor T1 for each of the eight test modes during operation with rapeseed oil, sunflower oil, soybean oil and diesel

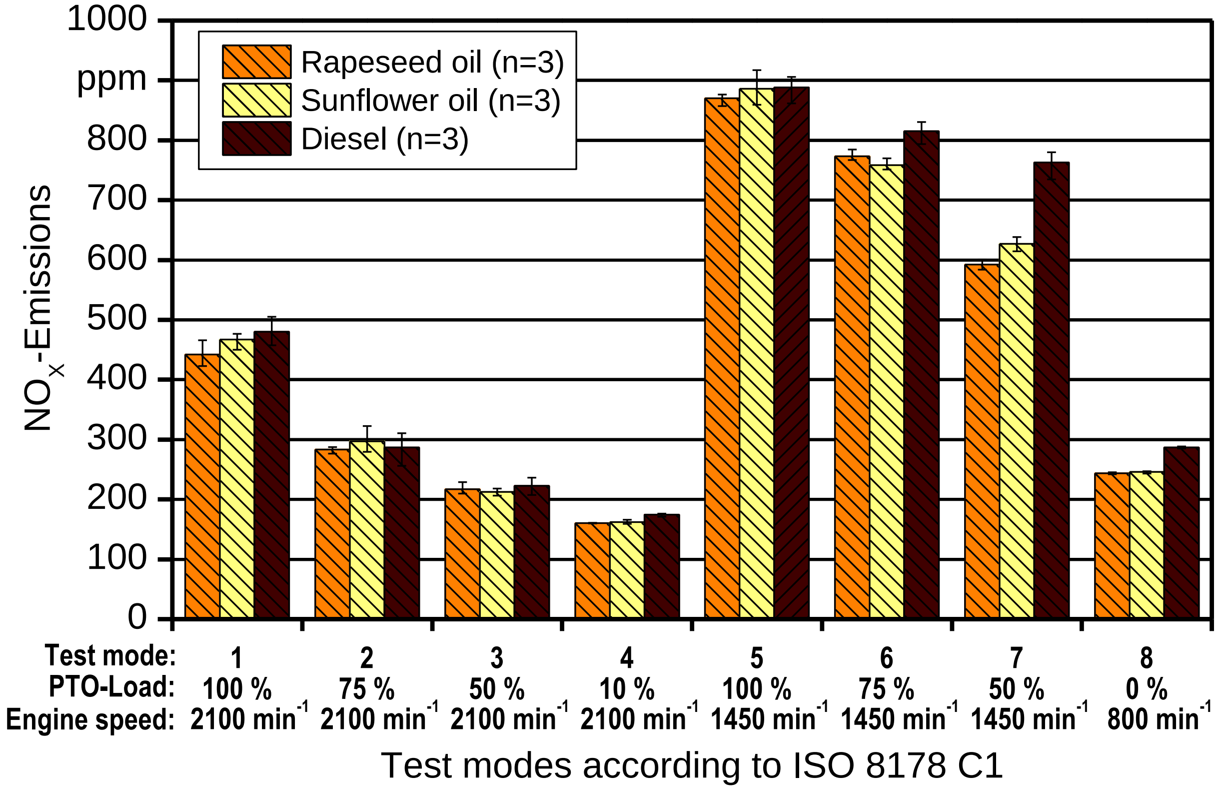

Figure 4: NO_X-emissions of tractor T2 for each of the eight test modes during operation with rapeseed oil, sunflower oil, soybean oil and diesel

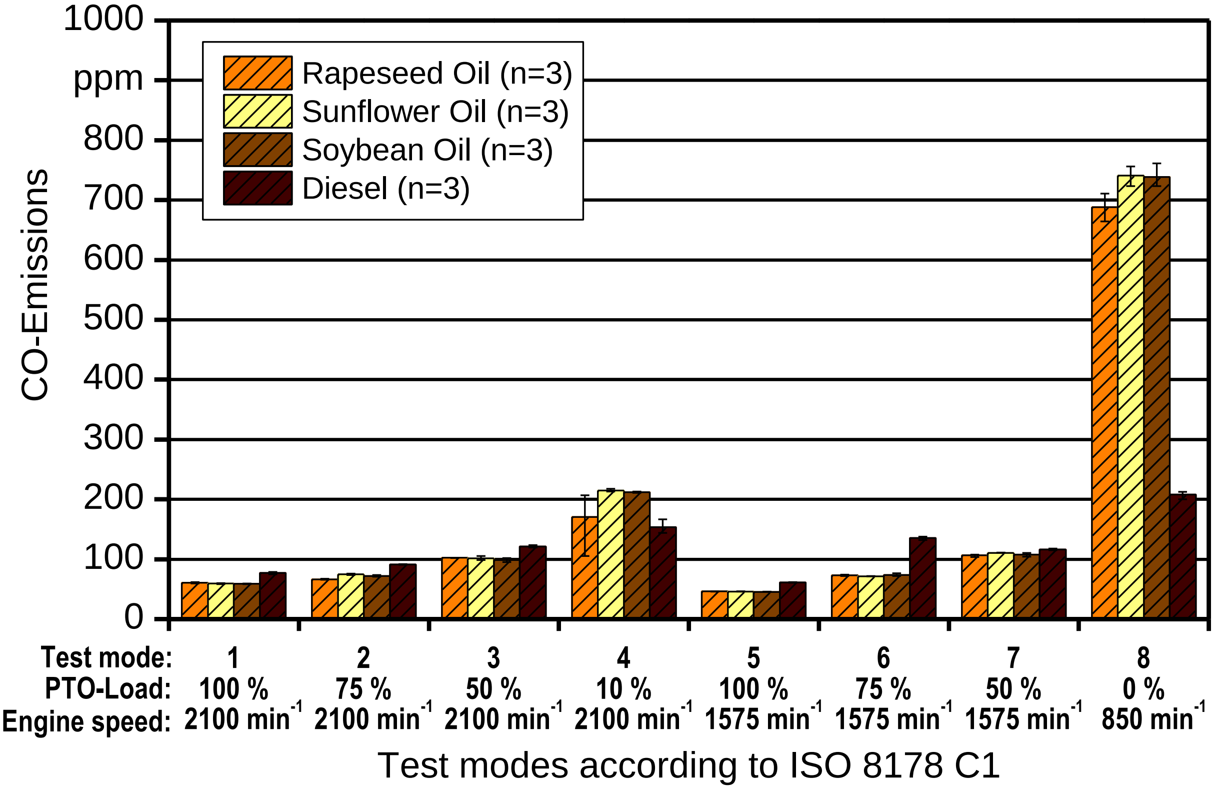

Figure 5: CO-emissions of tractor T1 for each of the eight test modes during operation with rape-seed oil, sunflower oil, soybean oil and diesel

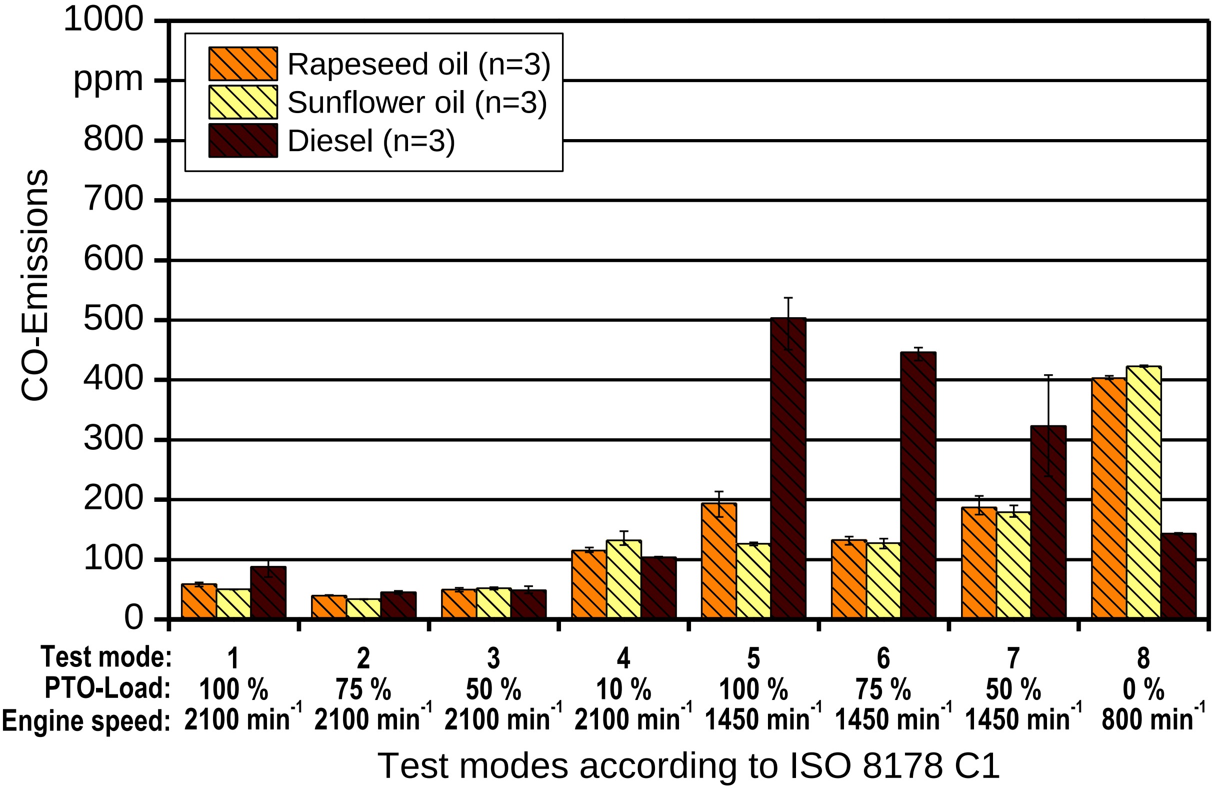

Figure 6: CO-emissions of tractor T2 for each of the eight test modes during operation with rape-seed oil, sunflower oil, soybean oil and diesel

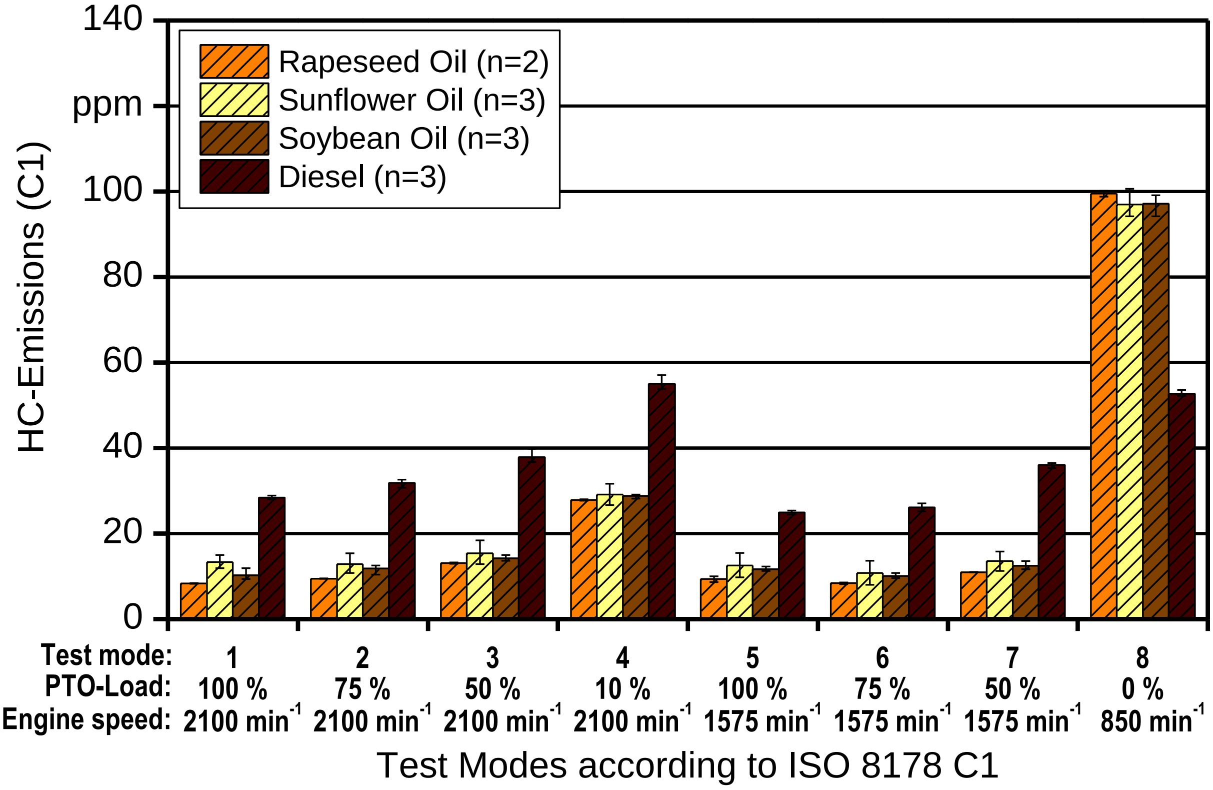

Figure 7: HC-emissions of tractor T1 for each of the eight test modes during operation with rapeseed oil, sunflower oil, soybean oil and diesel

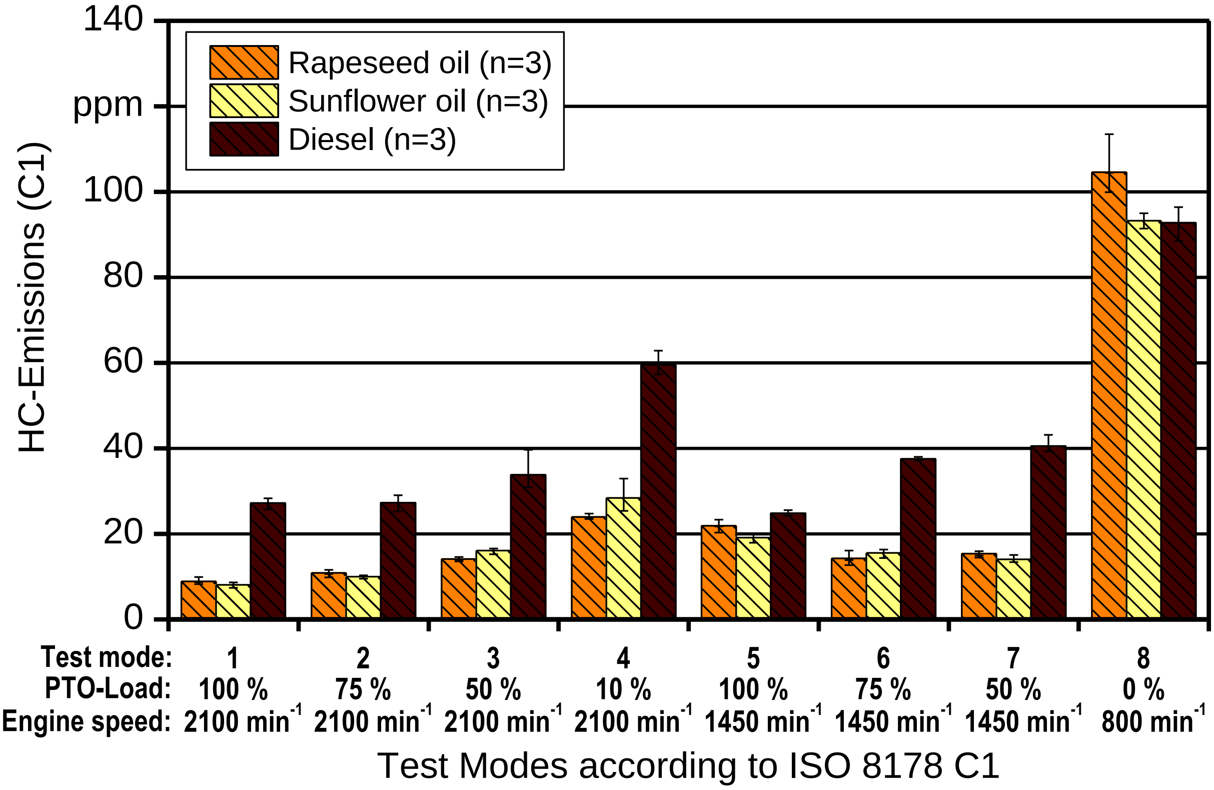

Figure 8: HC-emissions of tractor T2 for each of the eight test modes during operation with rapeseed oil, sunflower oil, soybean oil and diesel

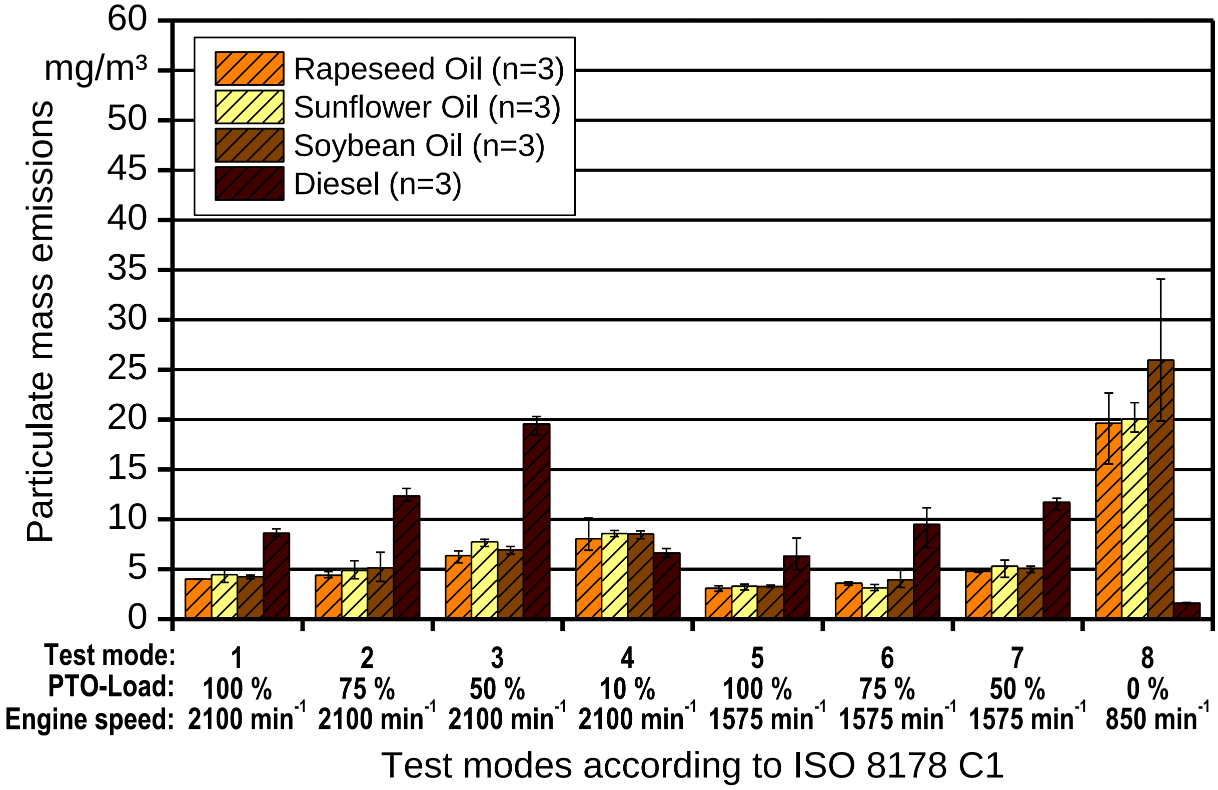

Figure 9: PM-emissions of tractor T1 for each of the eight test modes during operation with rapeseed oil, sunflower oil, soybean oil and diesel

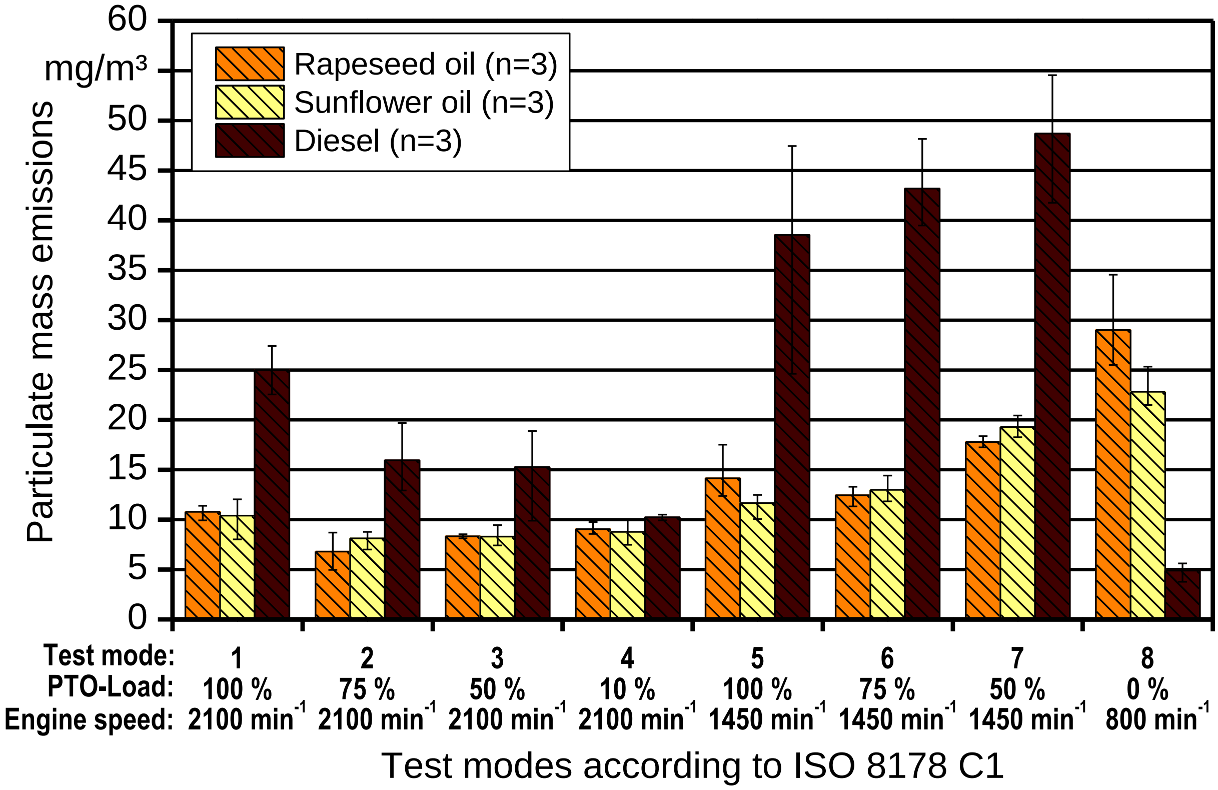

Figure 10: PM-emissions of tractor T2 for each of the eight test modes during operation with rapeseed oil, sunflower oil, soybean oil and diesel

The observed differences in the 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) [5] and Thuneke et al. (2009) [6]. For all ascertained emission components almost no differences in emission behaviour of the tested tractors by using rapeseed oil, sunflower oil or soybean oil could be observed.

Conclusions

Exhaust gas emissions of the tested new stage IIIA tractors are at a very low level, especially for CO, HC and particle mass. However, for both, diesel and vegetable oil fuelled tractors, further development is necessary to fulfil emission demands of exhaust gas stages IIIB and IV. Exhaust gas aftertreatment systems accompanied by fuels with low contents of ash forming elements can be one part of the solution. Besides rapeseed oil also other plant oils from sunflower or soybean can be a promising alternative for being used as a fuel in vegetable oil compatible tractors. Further research on the long-time behaviour of prospective plant oils are required and therefore plant oil quality needs to be standardised.

Acknowledgement

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